SCIENTIFIC MANPOWER

HEARING

BEFORE THE

SUBCOMMITTEE ON SCIENCE

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED SECOND CONGRESS

FIRST SESSION

JULY 31, 1991

[No. 60]

Printed for the use of the Committee on Science, Space, and Technology

U.S. GOVERNMENT PRINTING OFFICE

47-644 ⇆ WASHINGTON : 1991

For sale by the U.S. Government Printing Office
Superintendent of Documents, Congressional Sales Office, Washington, DC 20402
ISBN 0-16-035793-4

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CONTENTS

WITNESSES

CONTENTS

WITNESSES

SCIENTIFIC MANPOWER

WEDNESDAY, JULY 31, 1991

U.S. HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
SUBCOMMITTEE ON SCIENCE,
Washington, D.C.

The subcommittee met, pursuant to notice, at 9:35 a.m. in room 2325, Rayburn House Office Building, Hon. Rick Boucher [chairman of the subcommittee] presiding.

Mr. BOUCHER. The subcommittee will come to order.

This morning the Subcommittee on Science will explore issues associated with the supply and demand for scientists and engineers in the Nation's work force. Few public policy issues in science and technology are of greater significance.

A well-trained scientific and technical work force, sufficient in numbers and representing a wide range of skills, is an essential ingredient in the Nation's economic progress. This is the resource base that generates new knowledge and is the source of technological innovation that insures economic competitiveness and sustains a high standard of living.

In recognition of the importance of the scientific and technical work force, the Federal Government has long offered support for students pursuing studies in science and engineering. Beyond that, considerable effort is made by the Government to gather, maintain and analyze data to gauge the size, diversity and growth trends of the scientific and technical work force. This function of characterizing the scientific and technical work force has been largely the responsibility of the National Science Foundation.

Over the last several years, from a variety of sources, projections have been made of significant shortfalls in the future availability of scientists and engineers to meet the needs of industry, academia and government. These projections of shortages are based on such factors as analysis of demographic trends in the college-age population, trends in student preferences and attainment of degrees in science and engineering disciplines, and estimates of future personnel demands by industry, coupled with accelerating retirements on academic faculties. Projections of shortfalls in the scientific and technical work force are frequently cited in calls for greater efforts to increase the numbers of graduates in science and engineering. However, objections have been raised about the methodologies used in these projections, and those questions in turn raise concerns about whether they should be used to guide program planning.

We've asked our first panel of witnesses this morning to review the uncertainties and the problems that are associated with the

measurement of supply and the estimation of demand for scientists and engineers in the U.S. work force. We've also asked them to assess the level of confidence that can be placed in current projections of future shortages and to suggest ways to improve the accuracy of those estimates.

A second focus of this morning's hearing, which we have asked our second panel to address, is to review the National Science Foundation's actions to revise its data collection and analysis activities for national science and engineering manpower resources. At the request of the NSF, the National Research Council performed a thorough assessment of the National Science Foundation's data collection activities and issued a 1987 report entitled, *Surveying the Nation's Scientists and Engineers: A Data System for the 1990s.* The report makes recommendations for the better utilization by the National Science Foundation of data to be acquired from the 1990 Decennial Census. The report cited several serious weaknesses in the NSF scientific and personnel data system, criticized the inadequate resources devoted to quality control and improvement of personnel data surveys, and pointed out that NSF data have not always been readily accessible to the outside research community. A set of detailed recommendations was included in the report to address these identified problems. We've asked our second panel of witnesses to discuss the response by the National Science Foundation to that set of recommendations.

I want to extend the welcome of the subcommittee to our distinguished witnesses today and to thank both panels of witnesses for their attendance at this hearing. I'm sure that we'll be very enlightened by the testimony that they provide.

That concludes the Chair's opening statement, and it is my pleasure now to recognize the ranking Republican member of this subcommittee, the gentleman from California, Mr. Packard.

Mr. PACKARD. Thank you, Mr. Chairman. I, too, would like to join you in welcoming all the witnesses who will testify today on an area of great importance to the science community, the future of the United States scientific and technical work force.

Several studies have indicated that the United States will face significant shortages in the numbers of scientists and engineers as we move into the 21st century. Nevertheless, there are great discrepancies among the projections contained in these studies, which calls into question, as you mentioned, the methodologies which are being used to arrive at these numbers. It may be that we do not, at this time, know or understand all the factors that are involved in measuring supply and demand.

I do look forward to the testimony of the witnesses. It will be helpful, I think, in addressing the concerns that I have mentioned. I also look forward to the response of the National Science Foundation to the recommendations contained in the recent report from the National Research Council, and also from some of the university witnesses. So I am looking forward to this hearing and appreciate, Mr. Chairman, you scheduling it on this important subject.

[The prepared statement of Mr. Packard follows.]

STATEMENT OF
THE HONORABLE RON PACKARD (R-CA)
SCIENCE SUBCOMMITTEE
HEARING ON SCIENTIFIC MANPOWER
JULY 31, 1991
2325 RHOB, 9:30 A.M.

THANK YOU MR. CHAIRMAN,

I WOULD LIKE TO JOIN THE CHAIRMAN IN WELCOMING ALL THE WITNESSES WHO WILL BE TESTIFYING TODAY ON AN AREA OF GREAT IMPORTANCE TO THE SCIENTIFIC COMMUNITY -- THE FUTURE OF THE UNITED STATES' SCIENTIFIC AND TECHNICAL WORKFORCE.

SEVERAL STUDIES HAVE INDICATED THAT THE UNITED STATES WILL FACE SIGNIFICANT SHORTAGES IN THE NUMBERS OF SCIENTISTS AND ENGINEERS AS WE MOVE INTO THE 21ST CENTURY. NEVERTHELESS, THERE ARE GREAT DISCREPANCIES AMONG THE PROJECTIONS CONTAINED IN THESE STUDIES, WHICH CALLS INTO QUESTION THE METHODOLOGIES THAT ARE USED TO ARRIVE AT THESE

NUMBERS. IT MAY BE THAT WE DO NOT, AT THIS TIME, KNOW AND UNDERSTAND ALL THE FACTORS THAT ARE INVOLVED IN MEASURING SUPPLY AND DEMAND.

I LOOK FORWARD TO THE TESTIMONY TO BE HEARD TODAY -- IT WILL HOPEFULLY ADDRESS THE CONCERNS I HAVE MENTIONED. I ALSO LOOK FORWARD TO THE RESPONSES OF THE NATIONAL SCIENCE FOUNDATION TO THE RECOMMENDATIONS CONTAINED IN THE RECENT REPORT FROM THE NATIONAL RESEARCH COUNCIL.

THANK YOU MR. CHAIRMAN FOR SCHEDULING THIS TIMELY AND IMPORTANT HEARING.

Mr. BOUCHER. The Chair thanks the gentleman, and recognizes the gentleman from Illinois, Mr. Bruce.

Mr. BRUCE. I thank the Chairman.

Let me put an opening statement in the record and just congratulate the Chairman for this hearing on problems surrounding scientific manpower. There is a lot of conflicting data and information, but we all want to focus on bringing more people into the field of math, science, and engineering, especially women and minorities, both of whom are under-represented.

I'm happy to have with us today, on the second panel, one of the many women who are outstanding in the field, Mrs. Judith Liebman. Dr. Liebman is Vice Chancellor for Research and Dean of the Graduate School at the University of Illinois at Champagne-Urbana, located in my district. Her research includes transportation, energy management, health systems, mathematical optimization and model building, and the application of these in engineering. She has authored and co-authored more than 40 articles in these areas, and she comes today as the Chairman of the NSF Advisory Committee for Data and Policy Analysis. And I am happy to have her testify today.

I appreciate the Chairman's attention to this very pressing problem.

Thank you, Mr. Chairman.

[The prepared statement of Mr. Bruce follows.]

THE HONORABLE TERRY L. BRUCE
SCIENTIFIC MANPOWER
JULY 31, 1991

THANK YOU, MR. CHAIRMAN. I APPRECIATE YOUR ATTENTIVENESS TO THE FUTURE OF SCIENCE AND TECHNOLOGY IN THIS COUNTRY, AND I WELCOME YOUR LEADERSHIP IN BETTER UNDERSTANDING THE PROBLEMS SURROUNDING SCIENTIFIC MANPOWER.

THE PROBLEM OF PROVIDING OUR NATION WITH QUALIFIED SCIENTISTS AND ENGINEERS FOR THE COMING YEARS IS ONE THAT HAS BEEN DISCUSSED IN LIGHT OF DIFFERING AND SOMETIMES CONTRADICTORY, INFORMATION. HOWEVER, THE ONE THING THAT CAN BE AGREED ON IS THAT WE NEED TO FOCUS ON BRINGING MORE PEOPLE INTO THE MATH, SCIENCE, AND ENGINEERING FIELDS, ESPECIALLY WOMEN AND MINORITIES, BOTH OF WHOM ARE TRADITIONALLY UNDER-REPRESENTED IN THESE FIELDS.

WE ARE FORTUNATE TO HAVE WITH US TODAY, ONE OF MANY WOMEN WHO ARE OUTSTANDING IN THEIR FIELD, DR. JUDITH LIEBMAN. DR. LIEBMAN IS VICE CHANCELLOR FOR RESEARCH AND DEAN OF THE GRADUATE COLLEGE AT THE UNIVERSITY OF ILLINOIS IN CHAMPAIGN-URBANA. DR. LIEBMAN'S RESEARCH INCLUDES TRANSPORTATION, ENERGY MANAGEMENT, HEALTH SYSTEMS, MATHEMATICAL OPTIMIZATION AND MODEL BUILDING, AND APPLICATIONS OF THESE IN ENGINEERING. SHE HAS AUTHORED AND CO-AUTHORED MORE THAN FORTY JOURNAL ARTICLES IN THESE AREAS. SHE COMES TO US TODAY AS THE CHAIR OF THE NSF ADVISORY COMMITTEE FOR DATA AND POLICY ANALYSIS, AND I WELCOME HER BEFORE THIS SUBCOMMITTEE TODAY.

I WELCOME THE TESTIMONY OF OUR EXPERTS ON THE ISSUE OF SCIENTIFIC MANPOWER, AND THE COLLECTION OF RELEVANT DATA TOWARD ASSESSING OUR FUTURE WORKFORCE OF SCIENTISTS. THANK YOU.

Mr. BOUCHER. The Chair thanks the gentleman, and recognizes the gentleman from Maryland, Mr. Gilchrest.

Mr. GILCHREST. No comments, Mr. Chairman, I'm just looking forward to the testimony.

Mr. BOUCHER. We will now welcome our first panel of witnesses: Dr. Alan E. Fechter, the Executive Director of the Office of Scientific and Engineering Personnel for the National Research Council; Dr. Robert C. Dauffenbach, Director for the Center for Economic and Management Research of the University of Oklahoma; and Mr. Richard Ellis, the Director of Manpower Studies for the American Association of Engineering Societies.

Without objection the prepared statement of each of the witnesses will be made a part of the record. We would welcome your oral summaries and would ask that you keep your oral summaries to five minutes so that we'll have ample time for questions.

And Dr. Fechter, we will be pleased to begin with you.

STATEMENT OF ALAN E. FECHTER, EXECUTIVE DIRECTOR, OFFICE OF SCIENTIFIC AND ENGINEERING PERSONNEL, NATIONAL RESEARCH COUNCIL

Dr. FECHTER. Thank you, Mr. Chairman and members of the committee.

I first want to express my appreciation for your invitation to come here and share my thoughts on this thorny issue of projections of supply and demand with you. I also want to reiterate what I said in my formal statement. I'm here as a kind of a past modeler and student of labor markets and not in my capacity as the executive director of National Research Council's Office of Scientific and Engineering Personnel. And so the remarks I make and my views are those of my own and do not reflect those of the Research Council or its parent bodies, the Academies of Science or Engineering or the Institute of Medicine.

With those formalities past, let me get down to the nitty gritty of the topic. I'd like to devote my five minutes to try to stress and underscore several points I made in my paper. Let me start with what I call the four questions that I thought I was being asked to address.

The first question was, how much confidence do I place in the existing models of supply and demand that project the future? The second question is, what are the value of these kinds of efforts and, in effect the question, should we do these things at all? And if we do, how should we do them? The third question dealt with whether demography is destiny. That is to say, to what extent are demographic factors predominant with respect to these projections and is it valid to assume such predomination on the part of such demographic factors. And finally, what actions might one take to do a better job with respect to these efforts in the future.

Let me start with confidence. I would cite two reasons for lack of confidence in the existing models. One of these is the model—the structure of the models themselves. And what I mean by that is, do the models assume any kind of mechanism in the labor market to equilibrate disparities that might arise between supply demand? Some models do and some models don't. One of the models that

does not is the model that has been widely cited as justification for action for putting more money into student support for increasing the supply. And that is the shortfall—what I call the shortfall model.

That model assumes no relationship between supply factors and demand factors; so that, if there is a change in demand, it assumes the supply isn't going to adjust to that. The result of that kind of an assumption is, by and large, to overstate any kind of imbalance, either shortage or surplus that you might project out to the future; because the assumption is, there is nothing there to try to correct these things, which is going to go on forever and will accumulate and get worse and worse; and there is no mechanism to correct it.

On the other side, there are models which assume equilibration processes and my fellow panelist, Bob Dauffenbach, has been part of modeling exercises which do build an equilibration mechanism. And on the other side of that coin, of course, those equilibration mechanisms operate in a direction of assuming that things will work out. It biases the results in saying things will be okay—that supply—the people supplied and the number of people demanded will be equal so we'll move towards equality. And so you really can't look at the disparity between the numbers to tell you whether there are problems or not. And, in fact, in such models they look at things like immigration from other occupations as a possible indicator of potential problems. So one set of models operates in the direction of overstating the problems; the other set of models has a tendency to operate in the direction of understating the problem; and some place in between is the right answer.

The second issue that needs to be—that worries people with respect to these models, is the question of uncertainty. Many of these models, in trying to figure out what the future demand is going to be, have to make assumptions about a lot of other variables in the system to be able to come up with their answer. For example, the demand for scientists and engineers clearly is affected by things like what's going to happen to GNP—the rate of growth of GNP—the composition of that GNP in terms of things like how much of it is going to R&D, and how much of it is going to other activities, and even such factors as how much of it's going to defense or other science and engineering intensive activities, and how much of it's going to non-defense.

Those are things which we don't know for sure right now. And many of them, in fact, are policy variables which you people will be working on as part of your activities, so that uncertainty is something that is a reason for being skeptical about what these models can tell us.

But I would argue that this skepticism shouldn't mean that we should throw out the baby with the bath water. I believe that such modeling efforts are important. And while many people have said our inability to project-out things like GNP and demand are reasons for not engaging in such modeling efforts, I would argue that we ought to simply recognize the uncertainty in the way we do our projections. And we do that by simply talking about possible scenarios that might exist with respect to these uncertain variables that we are trying to get our hands on.

The work that was done by Dauffenbach and his colleagues in the equilibrium-type model, in fact, does deal with scenarios. It talks about a high and low growth scenario with respect to GNP, and it talks about high and low growth scenarios with respect to defense spending. And, indeed, the work they did in trying to project-out scientist and engineering supply and demand for the period 1982 to 1987, if I recall it correctly, the actual outcomes were bracketed by the scenarios that they arranged, so that at least the decision makers had a sense of where things might go. And that, I think, was something that was useful.

So we shouldn't give up on modeling. We should simply understand the uncertainties and document them in ways in which decision makers will be able to understand, so they'll know what the limitations are.

I spent a great deal of time and effort both in my *Bridge* article and my prepared statement laying out why I was skeptical of the shortfalls estimates that had been made and that are being widely cited around the country. At this point I simply want to state that, while I am skeptical of the numbers, I think the arithmetic that underlies the shortfall estimates are correct. But I am skeptical of the methods and assumptions that underlie that arithmetic, and that's where the problem lies. I think clearly, as I've stated in my *Bridge* article, we all—nobody disagrees with the statement that the demographics that we see in this country today are reason for concern, and we all should share that concern. I would say that the magnitude of the problem that we may face is not well illuminated by the numbers that have been generated by the shortfall estimates. They really are not very helpful.

Well then, let me go on to my second point, which is the value of modeling and whether one should do these things or not. While I've trained at the University of Chicago in economics—I might want to state that these models are useful. I would think that the options are either that we do these models, or we don't do these models. If we don't do these models, then we are, in effect, saying, we'll let the market take care of any problems that arise.

Now, although I am trained as a University of Chicago economist, I would like to state that the invisible hand does not operate through divine intervention. The invisible hand works because decision makers in markets read signals that are being sent on either the supply or demand side through wage/rate changes, price changes, other kinds of variables, job opportunities; they respond to those signals and that is what makes markets equilibrate. And these models, I believe, can be very helpful to those operators who are on both the supply and demand side of the market: students thinking about careers, employers thinking about whether they should be hiring more people or not. Those models are helpful in guiding these decision makers in moving in directions that we think may be appropriate.

So I think there is real value. I think the major value of these models is in informing policy. As I said in my prepared statement, I don't believe there is any intrinsic value to projections of supply and demand. These projections should be made with purpose. And, by and large, the purpose that should be served is policy making,

and I think most importantly policy making at the Federal level and here on this august Hill.

I think that in case of human resources, it's essential that we think ahead. Most of the human resource policy issues we face in this country—on this Hill—are human resource issues that deal with training, training the future supply of scientists and engineers. Creating that future supply takes a great deal of time. For engineers it takes four to five years at the bachelor's level. For people in sciences who go to the Ph.D. level, we're talking about 10 years before we can really see the impact of training policy. It takes 10 years to get people through the pipeline out—four years undergraduate, six years graduate training, by and large, so that we need to look ahead. And these models can be helpful in looking ahead, if they are properly structured and the questions that they are aimed at addressing are properly framed. And I talk to that in great detail in my testimony—in my prepared statement—excuse me.

The criterion that one should use, I think, for evaluating these future models should be whether or not they do, in fact, account for uncertainty. One of the main factors that needs to be dealt with is the fact that we don't know the answers to where things are going in the future. We need to look at a range of possible scenarios to be able to address that uncertainty and, hopefully, get answers from that range of possible scenarios that are pretty consistent across the scenarios—what I called in my prepared statement, robustness of the models.

If, in fact, the answers turn out to be roughly the same over a range of options, that's a pretty good model—that's giving you very good information—you could work with confidence using that information. So, I think, that if we go ahead with respect to this modeling effort, the models that should be produced are models that recognize uncertainty and deal with it in ways that are valuable to you all.

Let me not go into any further detail on that and move to the demographic issue because I think that informs some of the evaluations that I have made in my paper. Demographics—as I said in my paper demography is not destiny, but it is an important factor on both the supply and demand side of this market. On the supply side, research that I have done recently indicates very clearly that for a long period of time movements in the production of baccalaureate degrees in natural science and engineering fields mostly paralleled movements in the pool from which these baccalaureates are drawn. Now I use a slightly different pool than the shortfall's efforts have used. I used high school graduates lag four years as my basic source of new baccalaureates.

But in either case you find very strong associations between the period in the 1960s and the 1970s, between that pool—and movements in that pool and movements in the degree production rates that we observed. Someplace in the late 1970s, that relationship seemed to break down. That relationship was less strong in the 1970s and the 1980s than it was in the earlier period. And, by and large, nondemographic factors began to play a very significant role in explaining changes in degree production starting in the late 1970s and the 1980s. So on the baccalaureate level, on the supply

side, clearly demographics isn't the only factor. Certainly, it isn't any more, if it was in the past.

At the Ph.D. level it is even more so. There is absolutely no relationship between movements in the pool from which you get Ph.D.'s and Ph.D. production, and the reason for that is there are offsetting tendencies. You're getting large increases in the baccalaureate population from which you draw your Ph.D.'s. At the same time as that large increase was taking place in baccalaureate production, a large decrease was taking place in the portion of those baccalaureates that were going on and getting degrees. And I'm talking now only of American citizens and permanent residents. I'm not talking about the foreign part of this Ph.D. production, in the process. So there, clearly, demographics is not destiny and that decision making on the part of these young people at the undergraduate level going on to graduate school—it's very important—and, indeed, needs to be paid attention to.

On the demand side a similar situation exists. There the demographics really relate to the age composition of the science and engineering work force. That age composition is such that we can expect very large increases over the next 10 to 15 years in the numbers of retirements taking place in that work force. This should have an effect on the demand for new baccalaureates—if you have to replace these—and the demand for new Ph.D.'s. If you have to replace these retiring people, you are going to have to produce a larger number of baccalaureates and Ph.D.'s to meet that goal than you would have in the past. In fact, the dramatic aspect of that is, both for baccalaureates and Ph.D.'s, those retirement numbers are going to triple between now and the turn of the century. So this is not an insignificant factor to consider.

Finally, what about actions? What action should we be taking to deal with this problem of skepticism with forecasts? Well, my advisory committee at the National Research Council has been looking at these observations over time and one observation that I will share with you that comes from them is the observation that came from Eli Ginsberg, a renowned human resource specialist at Columbia University. His comment has been that this issue seems to be a hardy perennial. It never goes away. It comes back every four or five years to haunt us. Are we producing enough; are we producing too many? There is a cycle here that keeps coming back, and in his view we don't seem to make much progress in being able to address this question very well. And the question that we ask is, why?

In my opinion one of the answers to that question is, we don't give it consistent, concerted attention. And so as action, I think we need to think about ways of making sure that some competent people, scholars in universities, people with responsibilities for policy analysis in government, spend consistent time and resources to begin to start moving forward in our understanding of this problem. I believe that we would do that well—if we were to take past projection efforts and evaluate them based on what actually happened. Look at the difference between what happened and what was projected, and try to understand where we went wrong and, given that understanding, make improvements so that we wouldn't go as wrong, perhaps, in the future.

So I think that we need to devote energy and resources to this on a consistent basis, not just when it comes up every five or six years, which is basically the way we've been dealing with it in the past. We need to be able to deepen our understanding of these markets, both in terms of the equilibration processes that are involved and the behavioral parameters on the supply and demand side of these markets that need to be understood to make better projections in the future.

And, last but not least, we need to be able to track our performance in developing these models and these projections and getting a better understanding of that performance, in order to be able to move forward.

Thank you, Mr. Chairman.

[The prepared statement of Dr. Fechter follows:]

Projections of Scientists and Engineers: An Assessment

Testimony before the
Subcommittee on Science
Committee on Science, Space, and Technology

Alan Fechter
Executive Director
Office of Scientific and Engineering Personnel
National Research Council

July 31, 1991

I appreciate this opportunity to share with you my thoughts on the science and engineering human resource base. My formal remarks will focus on the topic for this panel: projections of future supply and demand and their value in public policy formulation. My credibility in addressing this issue is based on my activities as an erstwhile labor economist and modeler. Thus I must state at the outset that the views expressed in these remarks are mine only; they do not necessarily represent those of my current employer, the National Research Council or any of its parent organizations, the National Academies of Science and Engineering and the Institute of Medicine.

In addressing this topic, I shall deal primarily with the issues raised in Chairman Boucher's letter of invitation:

- the level of confidence that can be placed in current projections;
- the value of simulation and models in assessing the future;
- the value of demographic changes as predictors; and
- actions to improve the accuracy of these efforts.

Divining the Future: the Value of Modelling

Assessing future labor market conditions is a hazardous task. We are not even able to achieve consensus about current labor market conditions. Clearly, because of the uncertainties associated with it, efforts to gauge the future have been and will continue to be subject to even more contention.

Current modelling efforts. The question raised about the confidence that can be placed in current projections focusses on studies that have predicted significant shortfalls in the future supply of scientists and engineers. The most dramatic of these is the study by the National Science Foundation's Division of Policy Research and Analysis (hereafter referred to as PRA) that projects a cumulative "shortfall" of close to 700,000 bachelors degrees in natural science and engineering fields by the year 2011. I have expressed my misgivings about the estimates of engineering shortfalls generated by this study elsewhere. A copy of these comments, as well as the response from Peter House, Director of the Division of Policy Research and Analysis is included as part of my prepared remarks. My concerns are, by and on the large, equally valid for the results generated for the broader aggregate of natural sciences and engineering fields.

In sum, the study reflects the difficulties faced by most attempts to project supply and demand for these fields. These include:

- the difficulty of linking supply measures, typically formulated in terms of degree production, with demand measures, typically characterized by occupation; and

- a poor understanding of the dynamics of these markets -- especially feedback mechanisms that tend to bring supply and demand into balance.

The former difficulty arises because overlap between field of degree and occupation is not perfect. For example, those with degrees in natural sciences and engineering are not all employed in such occupations. And not all of those who are working in such occupations have natural science and engineering degrees.

The inability to link supply and demand makes it difficult, if not impossible, to project labor market shortages. This taxonomic obstacle is more serious in markets where the degree of overlap is weakest. Typically, it is more serious for scientists and engineers with bachelors degrees. And, at this degree level, the linkage is weakest for the social and behavioral sciences.

Analysts have attempted to deal with this problem in a variety of ways. For example, in attempting to assess the future for baccalaureates in natural science and engineering fields, the NSF study attempted to finesse the problem by explicitly projecting supply and by creating a "proxy" measure for demand that was based on degree production. My concern about this particular attempt to deal with the problem is described in the attached comment. I shall return to it below.

An alternative NSF model, developed by my fellow panelist, Dr. DauffenBach, and his colleague, Jack Fiorito, focusses on the occupational dimension and uses net immigration from other occupations as one indicator of potential shortage.

The second difficulty, our meager understanding of labor market dynamics, results in failure of many of these studies to consider feedback mechanisms, and results in a tendency to overstate future imbalances. The shortfall estimates generated by the PRA study assume no such feedbacks. Variations in supply are assumed to be based only on variations in the age-specific population.

Studies that do not account for such feedback generate worst case scenarios. This bias seriously limits the value of their findings. Decision makers may not be anxious to remedy potential problems that might not exist.

The value of modelling efforts. Despite these misgivings, I strongly endorse such modelling efforts as vital to policy formulation, particularly when it comes to the human resource base of our science and engineering enterprise. A major area of policy concern relates to programs intended to regulate the flow of talent through this educational pipeline at all levels. Given the long lead times required to acquire entry level degrees in these fields, ranging in most up to ten years beyond completion of high school, actions taken now to regulate these flows will not impact on these labor markets for many years. Thus, the task of anticipating the future becomes a virtual necessity for policy formulation.

Properly used, simulation/modelling techniques provide powerful tools for illuminating this future. Your questions suggest your awareness of the difficulties involved in attempting to project the future. Uncertainties abound with respect to key long term determinants of supply and demand. On the demand side, what will be the long term trend in: real GNP? real R&D expenditures? defense and aerospace activities? On the supply side, what will be the long term trend in: the pool from which scientists and engineers are drawn? the proportion of that pool interested in pursuing careers in science or engineering?

Simulation/modelling efforts can illuminate the future by producing "what if..." scenarios about these trends and evaluating their supply/demand implications. But these efforts will not necessarily be of equal value.

For example, there is no objective way of assessing which scenario will be the correct one. Thus, the value of such efforts will depend significantly on the relevance and reality of the scenarios chosen. Other things equal, models that are based on credible scenarios will be of more value. Some of my misgivings about existing shortfall estimates are based on this criterion.

There are other factors to be considered in evaluating these models. I would emphasize three: simplicity, robustness and accuracy of forecasts. The first characteristic, simplicity, is a criterion frequently used by scientists in judging alternative theories rationalizing observed phenomena. Other things equal, simple explanations are better than complicated ones. The PRA study scores well on this account.

The second factor, robustness, describes the stability of findings for alternative scenarios. Given the uncertainties

associated with projecting the future, it is prudent to specify a range of possible scenarios that hopefully brackets the one that is ultimately experienced. Other things equal, more robust models are better than less robust models. Some studies have been exemplary in their efforts to emphasize the range of uncertainty associated with their forecasts; others limit their projections to only one scenario, thereby giving a distorted impression of the degree of certainty associated with their findings. The PRA study falls in the latter category; the DauffenBach/Fiorito study falls in the former category.

The third factor, forecasting accuracy, is the ultimate and most difficult test. It requires comparisons of predicted to actual values. Of course, such comparisons are not possible until a significant amount of time has past. Nevertheless, I believe all efforts to project future supply and demand should be subject to this type of analysis. Based on the findings emerging from such an analysis midcourse corrections can be made in model parameters and assumptions. Such corrections can improve the accuracy, and hence the credibility of these modelling efforts.

While there are compelling reasons for attempting to assess the future, there are equally valid reasons why these efforts should be limited to situations in which they will add significant value to the policy formulation process. In and of themselves, such assessments of the future have little intrinsic value.

My major misgiving about the shortfall estimates is related to this point. The policy concern is whether, given expected demographic patterns and current levels of student support, the flow of new talent into science and engineering labor markets will be sufficient to meet the future needs of the science and engineering enterprise. If it will not be, policy action (such as increasing the amount of student support provided) may be required. To effectively address this issue, decision makers need information on future flows of talent (supply) and future needs for this talent (demand). (They will also need information about the impact on supply and/or demand and the costs of alternative policy measures.)

As noted above, there are taxonomic obstacles to attempting to link supply and demand. The shortfall estimates are based on one particular approach to this obstacle--to develop a "proxy" indicator of demand expressed as the average number of bachelors degrees produced in these fields at an arbitrarily selected period of time in the past. I believe, however, that a more appropriate approach would be to ask the question: how rapidly do we want the pool of potential workers with degrees in a given field (or set of fields) to grow over a future period of time?

The answer to this question is derived from a set of

variables that are determined by higher order policy objectives. These include the expected rate of growth of real GNP, the rate of growth of real R&D expenditures, and the composition of both real GNP and R&D. The answer must also consider other relevant factors, such as expected college and graduate school enrollments and desired student/faculty ratios. Formulated in this way, one can assess the level of degree production required to attain this growth.

Given this formulation, one can assess the shortfall estimates for baccalaureates generated by the PRA study in terms of the annual rate of growth of the population with baccalaureate degrees in natural science and engineering fields consistent with the proxy specified in the NSF model--the average annual 1984-1986 number of bachelors degrees produced in these fields.

Based on crude estimates of the baccalaureate population, I estimate this rate was almost four percent per year in the late 1980's. Because of an expected rise in the number who will be retiring over the next 15 years, documented below, this rate will fall to the 2 1/2-3 percent range in the 1990's. It will fall further to the 2 percent range in the first decade of the twenty-first century.

Addressing the issue in this way focusses decision makers on the important policy question--whether these rates of growth are feasible and desirable--and minimizes unnecessary preoccupation with methodological and technical issues.

Demographic Changes as Predictors

Demography factor is an important, but not the sole, determinant of future supply and demand. On the supply side, one can decompose observed changes in degree production into elements: changes in the size of the pool from which degree recipients and be drawn (defined as the number completing the next lowest level of education, lagged the appropriate number of years) and changes in the fraction of that pool who choose to acquire science or engineering degrees. Recent research suggests that each of these factors has been an important determinant of past changes in the number of degrees produced in natural science and engineering fields at both the bachelors degree and the doctorate levels.

The relative importance of these elements has varied over time and across degree levels. For bachelors degrees, changes in the size of the pool were the dominant factor until the late 1970's. In the 1980's changes in bachelors degree production were driven primarily by changes in the fraction of the pool who chose to acquire degrees in these fields.

At the doctorate level, the relatively stable annual number

of domestic new doctorates (i.e. the number of doctorates awarded to U.S. citizens and non-citizens with permanent resident status) experienced in the late 1970's and 1980's was the product of a dramatic increase in the pool and an equally dramatic decrease in the fraction of that pool who acquired doctorates in these fields.

Demographics is also important on the demand side of these markets. The composition of the science and engineering population with respect to age is the dominant determinant of replacement demand (i.e. the number of new degrees required to replace those who retire or die).

Given the current age composition of the populations with bachelors degrees and doctorates in natural science and engineering fields, replacement demand can be expected to triple over the next 15 years (from roughly 33,000 in 1990 to 95,000 in 2005 for bachelors degrees, and from roughly 4,000 in 1990 to about 11,000 in 2005 for doctorates). I consider these expected trends to be reasonably reliable.

The bottom line that emerges from this discussion is that although it is an important determinant of supply and demand trends, demography is not destiny. Nondemographic factors also play important roles. Thus, failure to account for these nondemographic factors in supply/demand projections will reduce the reliability of these projections.

Actions to Increase the Accuracy of Projections

The discussion to this point has suggested a number of possible actions to increase the accuracy of supply/demand projections. The major ones include:

- Assessing the forecasting accuracy of projection models and making appropriate midcourse corrections;
- Building market feedback into the projections models; and
- Deepening our understanding of the nondemographic determinants of supply and demand.

The latter two involve acquiring a better understanding of the dynamics of these important labor markets.

A new NSF program to fund research on the determinants of science and engineering supply and demand constitutes a significant first step in this direction. This program needs to be nurtured and supported. Its aim should be to produce a

critical mass of researchers who are actively engaged in expanding the frontiers of knowledge on this topic.

Sustained and systematic efforts to:

- identify the key supply and demand variables;
- estimate their parameters; and
- better understand the complexities of the equilibration process experienced in these markets

will ultimately yield more credible projections.

Alan Fechter

Engineering Shortages and Shortfalls: Myths and Realities

Demographic projections have given rise to concerns about this nation's ability to meet its future need for engineers

Alan Fechter is executive director of the National Research Council's Office of Scientific and Engineering Personnel. This article is adapted from remarks presented at the Sixth Convocation of Professional Engineering Societies and the National Academy of Engineering on 31 May 1990. The views expressed in this article are those of the author. They do not necessarily reflect those of the National Research Council or its parent organizations, the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Demographic projections have given rise to concerns about this nation's ability to meet its future need for engineers. A number of models have been developed to determine whether these concerns are warranted. In recent months the findings generated by one of these, the model created by the National Science Foundation's Division of Policy Research and Analysis (PRA), have been gaining prominence. This model projects a cumulative "shortfall" of 275,000 engineering graduates by the year 2011.

This dramatic conclusion has created a considerable amount of controversy. Many people have expressed skepticism about its validity, while others have embraced it unquestioningly as evidence of the need for action. In part, the wide range of reactions may stem from a lack of familiarity with the nature and structure of the PRA model, which has not been published in the open literature—and thus, has not been subject to the rigorous scrutiny of peer review.

The objective of this paper is to remedy this deficiency. PRA has developed two sets of projections: one for baccalaureates and one for doctorates. This paper will focus on baccalaureates since they are the most numerous component of the engineering community.

Model Structure

Market imbalances (i.e., shortages or surpluses of engineers) are generally defined as the difference between supply and demand. The concerns arising from the demographic projections can be summarized as a fear of such an imbalance—specifically, that there will be an inadequate supply of engineering graduates to meet future national needs. Thus, the modeling efforts have been aimed at projecting future engineering supply and demand.

The PRA model defines engineering supply as the number of bachelor's degrees produced in engineering fields. This supply is assumed to be equal to the product of two variables: a demographic variable, which provides an indicator of the size of the pool from which engineering graduates are drawn, and the fraction of that pool who acquire bachelor's degrees in engineering. This supply relationship is tautological rather than behavioral; it is true by definition and, in consequence, it cannot be refuted.

The model defines the pool from which engineering graduates are drawn as the number in the 22-year-old cohort. The trend in this number has been downward since the middle of the 1980s (Figure 1).

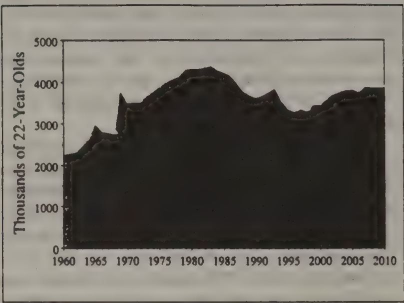

FIGURE 1 The decline in the U.S. college-age population continues until the late 1990s.

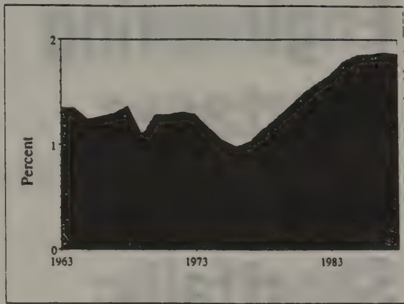

FIGURE 2 The U.S. engineering participation rate, the fraction of the college-age population earning engineering degrees, has increased since the mid-1970s.

The fraction of the pool acquiring degrees in engineering is defined as a "participation rate"—i.e., the number of bachelor's degrees awarded in engineering per hundred 22-year-olds. The trend in this fraction has been sharply upward since the middle of the 1970s (Figure 2).

Treatment of demand is more ambiguous. Demand is not explicitly defined; instead, the model considers a "proxy" for demand, defined as the annual production of bachelor's degrees in a given base year.

The reason given for finessing the direct treatment of demand is the conceptual difficulty in identifying the employment of those who have acquired engineering skills by completing bachelor's degrees in engineering fields. The difficulty arises from the mismatch between labor market data, which are occupationally oriented, and education data, which are organized by academic discipline. Many engineering graduates use their skills productively in occupations not officially counted as engineering occupations; and many in engineering occupations do not have engineering degrees. These mismatches make quantitative projection of demand highly uncertain.

PRA argues that use of engineering degree production in a base year as proxy produces a conservative estimate of demand because it limits future replacements and increases in demand to a fixed number of new graduates.

Model Projections

There are several versions of the PRA model—some published, some part of the background literature, and some about to be published. The assumption made in the earliest model was that the participation rate would remain steady at about 1.67 percent, the level found for 1983. Given this assumption, future changes in degree production would result only from changes in the population pool from which these degree recipients are drawn. The data summarized in Figure 2 clearly show that this assumption is not valid. The participation rate averaged 1.42 percent for the 40-year period, 1959–1988. It varied from 0.98 to 1.88 percent, a range of over 90 percent, over this period. Between 1983 and 1988 the rate rose from 1.67 to 1.86 percent, an increase of almost 20 percent.

In the most recent version, the model relaxes its stringent assumption about participation rates. Instead, based on evidence from a University of California at Los Angeles survey of freshman career intentions, it assumes that the rate will fall from its 1988 value to approximately 1.6 in 1992, after which it will gradually rise again to about 1.7 in 1998. It is further assumed that, after 1998, the participation rate will stabilize and remain at the 1998 level.

The demand proxy varies with the version of the model examined. It is either the 1983 level of degree production or the annual average of 1984–1986 degree production. Both expressions of the demand proxy represented historic highs at the time these models were formulated (Figure 3).

The PRA model defines "shortfall" as the cumulative difference between proxy demand and supply. In other words, a shortfall is defined as the amount by which annual engineering degree production falls

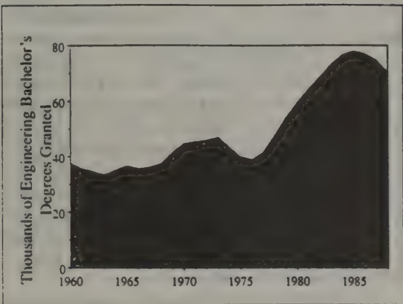

FIGURE 3 Annual production of engineering bachelor's degrees, the proxy for demand for engineers, peaked around 1984.

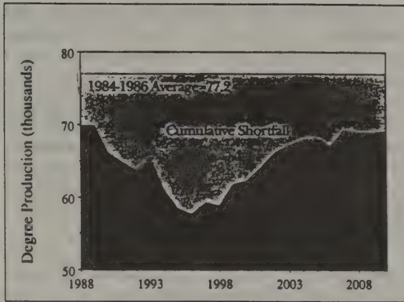

FIGURE 4 Cumulative shortfall of engineering bachelor's degrees, 1988–2010. Shortfall=1984–86 average annual number of engineering bachelor's degrees produced minus projected degree production.

below the average experienced in 1984–1986, cumulated over the years 1988–2011 (Figure 4). Based on this definition, the model projects a cumulative shortfall of 275,000 engineers.

Evaluation of Model

Responsible practitioners of the art of simulation modeling are aware of the limitations of an activity that, in earlier times, used the entrails of chickens as a tool of analysis. Consequently, they practice their art with humility and offer their results with a great deal of modesty. Such practitioners often undertake sensitivity analyses and provide a range of projections to underscore the uncertainty associated with their assessments. Unfortunately, the PRA model produces only one set of estimates, ignoring the important issue of uncertainty.

This failure to acknowledge uncertainty can be pernicious, in that it can seduce the unsuspecting user into believing that the results are more robust than they actually are, given the model's assumptions and definitions. As noted earlier, the model makes a number of arbitrary assumptions about the nature of supply and demand and about future values of these variables.

The model considers only degree production, excluding other sources of supply from its analysis. In engineering, mobility from closely related fields has traditionally been an important source of supply. Moreover, even when the analysis is restricted to degree production, the projections of participation rates for the years beyond 1992 have little factual basis. The degree production projections for 1988 to 1992, generated by participation rates based on freshmen intentions data, are probably reasonable. But the assumption that these rates will slowly rise and level off appears quite arbitrary. Figure 2 shows that these rates can exhibit a considerable range of variation.

Other things being equal, bachelor's degree production can be expected to vary equiproportionately with changes in participation rates, if we accept the tautological supply relationship postulated by the model. Given this expectation, sensitivity analysis would illuminate the range of uncertainty associated with the arbitrary selection of post-1992 participation rates.

The concept used for demand also needs closer scrutiny. As noted above, a proxy for demand is used: average degree production for 1984 to 1986. Implicit in that number is some growth rate in the work force with engineering skills. Arguing conceptual complexity, the PRA model did not examine this growth rate and chose instead to represent demand with one particular proxy. Other proxies can be examined to assess the sensitivity of the particular demand proxy used by the model. To illustrate, I examined the data published by the Bureau of Labor Statistics (BLS) and the National Science Foundation (NSF) to determine the growth rate of the work force with engineering skills in the 1980s, the period for which the model's proxy demand applies. I chose these two particular sources since they provide rough boundaries on the true estimates. The NSF estimates reflect

the broadest available operational definition, combining information about degree field, occupation, and professional self-assessment. The 1988 NSF estimate was 2.615 million. The BLS estimates reflect a narrow occupational definition. The 1988 BLS estimate was 1.805 million. The average annual rate of growth exhibited by the NSF data for the period 1980–1988 was 10 percent; the rate exhibited by the BLS data for the same period was 3.5 percent. I believe the NSF estimates provide an upper bound on the estimated growth rate, while the BLS estimates represent a lower bound.

Given the growth rates of these proxies, a lower level of degree production than the 1984-1986 annual average rate might be expected to result in projected annual growth rates of less than the 3.5 to 10 percent range exhibited by these alternative proxies.

As a cross-check on the growth rate analysis described above, assuming that no degree recipient leaves the population on or before the age of 65 and all degree recipients leave at age 66, I cumulated bachelor's degree production in engineering fields for the period 1945–1988 as an estimate of the 1988 population with bachelor's degrees in engineering from U.S. institutions. The number was 1.9 million, about 37 percent below the proxy based on NSF data and about equal to the proxy based on BLS data. If all degree recipients who reach the age of 65 between 1988 and 1992 must be replaced by new graduates, the replacement rate will be approximately 1.4 percent. Given this replacement rate, the number of engineering degrees required to support alternative target growth rates for this period is summarized below:

Target Annual Growth Rate	Annual Number of Engineering Degrees Required
0 percent	23,000
2 percent	63,000
4 percent	105,000

The 1984–1986 degree-production target represents roughly 4 percent of this population. Thus, the target annual growth rate implied by the PRA model's estimate of proxy demand would be about 2.6 percent. Recognizing the constraints imposed by projected slower population growth and reduction in defense expenditures over the next decade, the Bureau of Labor Statistics projects employment in engineering occupations to grow at an average annual rate of 2.5 percent between 1988 and 2000, down from the 3.5 percent rate experienced between 1976 and 1988 and about equal to the growth rate implied by the crude cohort survival model described in the preceding paragraph (Silvestri and Lukasiewicz, 1989). The projected reduction in degree production generated by the PRA model for that period implies an average annual growth rate in the number of engineers with bachelor's degrees in engineering fields of about 2.2 percent for that period.

The model also suffers from a more generic shortcoming. Most of the simulation models used to assess these labor markets assume that markets do not equilibrate; that if an imbalance occurs between supply and demand, nothing will occur to correct it. In fact, history demonstrates that these labor markets do tend to equilibrate (Freeman, 1976; Ginzberg, 1986). Thus, projected imbalances derived from such models—both shortages and surpluses—are always overstatements of what actually will be experienced.

The model considers only degree production, excluding other sources of supply from its analysis.

The relevant policy issue should be whether the expected equilibration mechanisms triggered to correct these imbalances will be consistent with national needs and more global social objectives. For example, if an engineering shortage is expected, will employment of physicists, chemists, mathematicians, and others who are competent to do the work of engineers be a satisfactory means of addressing this shortage? Alternatively, will immigration from other countries be satisfactory? If not, then policymakers will need to consider other mechanisms that will equilibrate supply and demand with minimal unwanted side effects (National Research Council, 1988).

Policy Contributions

Given the shortcomings discussed above, the PRA model is not very useful for policy formulation. Boiled down to its essence, the model simply reinforces the common-sense notion that adverse demographic trends will make it more difficult in the future to produce a given number of engineering graduates. But the model does not provide meaningful information on whether we will need to recruit this number. Moreover, it does not provide a strong factual base for evaluating the types of measures that could or should be taken to alleviate potential problems. For example, the shortfall generated by the model does not constitute a meaningful statistical basis for deciding whether and by how much to increase student support. Instead, it produces a number, an estimated 275,000 shortfall, the magnitude of which in the minds of many implies a situation of crisis proportions.

How much growth do we want to see in our pool of engineering talent?

Failure to document fully the strengths, limitations, and degree of uncertainty associated with this number can ultimately undermine the credibility of simulation modeling—a method of analysis that can potentially shed light on important human resource policy issues—especially if the crisis predicted by this model does not occur.

A more fruitful strategy would be to deepen our understanding of demand. The critical questions to be addressed include: How should we define demand? Can we construct an operational definition of demand that will yield meaningful estimates? How much growth do we want to see in our pool of engineering talent? What constraints exist as barriers to such growth? How can we accommodate those barriers? The answers to these questions will better inform policy than the fanciful shortfalls generated by the PRA model.

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Letter
NSF Projections in Science and Engineering

We agree with many of the statements in Alan Fechter's article "Shortages and Shortfalls: Myths and Realities." However, the myths he refers to are largely created by misinterpreting our work, and he provides few realities that contribute to better understanding of the issue. The "PRA Model" to which he refers is but a projection of a specific historical stability, made to point out what would happen if it remained stable. Fechter is one of the few people who glorify this simple process with the term "model." We introduced this approach in to the debate five years ago; it applies to a specific aggregation level of fields, namely, natural sciences and engineering (NS&E). We have repeatedly emphasized that our simple extrapolation procedure is most valid for NS&E; at higher or lower aggregations of science and engineering fields (such as engineering by itself), the relationships are much less stable. Our analysis is documented in a working paper titled "Future Scarcities of Scientists and Engineers: Problems and Solutions," which has undergone several updates over the past years, as we have received comments from dozens of our peers. Readers who would like a copy should contact the NSF Division of Policy Research and Analysis at 202/357-9689.

The bachelor's degree portion of our analysis is based largely on the following empirical relationship. There is considerable variation in B.S. participation rates (ratio of degrees granted to 22-year-old population in the same year) in the various subfields of NS&E, but the variations are largely complementary, yielding a very stable participation rate for the combined fields. We found no reliable way to confidently project participation rates for the higher or lower levels of field aggregation. Nevertheless, Fechter deals only with engineering; that is not what our paper is about. It is true, we presented a "shortfall" number for engineering, but it was a ballpark number based on the current engineering share of NS&E bachelor's degrees. This estimate was made to roughly indicate the relative size of a major component part of the NS&E B.S. shortfall. Our projection method is not used to project bachelor's degrees in engineering, or in any other subfield.

Second, Fechter stretches our projection of a declining number of NS&E B.S. degrees into a job market shortage, which we never intended. An entire section of our paper explains why we selected the noneconomic term "shortfall" as opposed to the term "shortage." Had we had a robust grasp on future demand for NS&E bachelor's degrees, we would not have had to define a "shortfall" concept at all. The Ph.D. section of our paper actually includes a straightforward economic, market-clearing, supply–demand model, because there are empirically stable demand determinants for new NS&E Ph.D.'s. Most employment analysts recognize that demand projection is much more difficult for NS&E B.S. degrees. We did not prepare a market analysis for B.S. degrees. Several national experts on this issue concur with this judgment, and the 1985 NRC report *Engineering Education and Practice in the United States* points out the futility of demand projections for engineering skills.

Below are some specific points, ordered as in Fechter's article.

- We do not "[define] engineering supply as the number of bachelor's degrees produced in engineering fields" (p.16). Our focus was simply on the future production of NS&E bachelor's degrees, using the assumption that the economy can use at least as many every year as have been produced in the recent past.

- No assumption was ever made about the participation rate in engineering, as is erroneously stated on p.17. The rest of that paragraph completely misses the basic point of the NS&E participation rate stability, as noted above: prospective NS&E majors seem to have chosen various

fields within that set largely at the expense of other fields in that set. We have never made any claim about the stability of participation rates in engineering taken by itself. Figure 2 is a straw man (indeed replicates part of a PRA figure which shows the more aggregated NS&E participation rates as well, demonstrating the variation in stability noted above).

- Fechter claims that we fail to acknowledge the uncertainty of our projections, p. 18. To the contrary, we stated clearly that this was an "if...then" analysis: if these historical relationships continue, and without specific interventions, and before the market clears as we acknowledge it will, then these are the implications. On the very first page of our paper, we state: "The analyses in this paper have used trend projections [of] past relationships between variables only if these are stable in the sense that they have held for years, in a few cases, decades. All such assumptions about the persistence of past trends and relationships have been identified, and the analyses should be interpreted as conditional on their continuation."

- We should not be criticized for not acknowledging sources of supply other than new bachelor's degree earners (p. 18), since we did not undertake to analyze the "supply" of NS&E personnel.

- On page 19, Fechter points out that our degree projection may not be consistent with NSF and BLS estimates of the growth of the engineering work force. Again, the only appropriate comparison would be for NS&Es. That comparison would be interesting but the concepts being measured are so different, thus requiring a number of assumptions to infer a work force growth rate from a projection of bachelor's degrees, that it would not provide a very powerful check on the projections. A better check of the projections is simply the actual number of bachelor's degrees in NS&E. For the 2 years of data that have come out recently, 1987 and 1988, the decline in the number of NS&E bachelor's degrees has been almost as we projected.

- We agree with Fechter that "the relevant policy issue should be whether the expected equilibrium mechanisms triggered to correct . . . imbalances will be consistent with national needs and more global social objectives" (p. 19). Our efforts were intended to stimulate discussion about the consequences of a potential downturn in NS&E degrees.

- Fechter claims that failure to document uncertainties associated with the number can ultimate undermine the credibility of simulation modeling. But (1) the B.S. projections are not simulation modeling, and (2) our paper contains discussions of uncertainty.

- He also believes that "the integrity of those who associate themselves with the model's findings" will be "seriously undermined", "—especially if the specter of crisis implied by this model does not occur". It is statements of this sort that, in addition to the misinterpretation of our paper itself, makes Dr. Fechter's piece particularly difficult to treat as an even-handed critique.

The questions with which Fechter concludes his argument are the right questions. Valid answers would better inform policymakers than our projection of historical relationships. But they are very difficult questions, and Fechter has not helped answer them.

Peter W. House, Director
Division of Policy Research and Analysis
National Science Foundation

Editors' Note: Peter House's comments are based on a prepublication copy of the article by Alan Fechter that appears on pages 16-20 in this issue.

Mr. BOUCHER. Thank you, Dr. Fechter.

Dr. Dauffenbach, we'll be happy to hear from you.

STATEMENT OF ROBERT C. DAUFFENBACH, DIRECTOR, CENTER FOR ECONOMIC AND MANAGEMENT RESEARCH, UNIVERSITY OF OKLAHOMA, NORMAN, OKLAHOMA

Dr. DAUFFENBACH. Thank you.

I am grateful for the opportunity to appear before the Subcommittee on Science to discuss science and engineering, S&E personnel issues. I want to thank Alan for his kind remarks on my work and also to say that I share his concern that the invisible hand is all thumbs.

There are many issues that we face as a Nation regarding this very small component, but very important component, of the work force. In all likelihood competitive success of this Nation rests on its ability to cultivate science and engineering enterprise. Faced with problems in science and math education in our public schools, fewer young people in the college-age cohort, an increasing dominance of women and minorities in the work force, who have not been traditional sources of supply in almost all science and engineering fields, dramatic growth in the share of U.S. Ph.D.'s awarded to foreign nationals, and pressures internationally in R&D performance, our concern is not surprising.

But just how concerned should we be? We obviously need data and analysis to appraise the extent to which our concerns are real and require direct action. I've been asked to comment on a number issues related to predicting the future of S&E labor markets. I've been presented with a very tall order, but I'll attempt to provide some insights in the short time available to me.

I've engaged in a fair amount of research on S&E labor markets, including recently input on S&E supply/demand balances in the 1990s for the forthcoming *Science and Engineering Indicators* report. Obviously I believe in economic modeling. Obviously, too, there are many uncertainties and problems in trying to predict the future. Despite these uncertainties, there is great value in models and simulation. Their value lies in the wealth of alternative futures that can be processed through them. While we cannot predict the future, we can look at alternative futures and their implications. We need not confine ourselves to one vision of the future. Also, simulations get the assumptions out on paper. They set the foundations for debates on the probable future course of events. The features that models embody should also tell us something about what the researcher thinks is important, how the market works as that model takes shape and conveys its components. And, certainly if we don't do simulations, we're not going to get any better at them.

I've attached to this testimony a brief review of supply/demand models currently in operation in the division of Science Resource Studies. I'm talking about the SRS, not the Policy Research and Analysis Division (PRA). These are different models and I would add that—the PRA approach that's added a lot of controversy lately and I would suggest also that these models are grounded in classical input/output manpower forecasting techniques. Now the

summary materials I have provided are still somewhat technical, but a quick reading will reveal the key components that economists feel are important to include in these type of models.

There are a few comments that I would like to make on issues related to the size of the work force and flexibility of the S&E work force. First, the small size of the S&E work force makes for special problems. Approximately only 1 in 1—1 in 100—4 in 100, excuse—approximately 4 in 100 employed persons in the U.S. work force is a scientist or an engineer. If the sample base—when we create samples upon which to gather information on scientists and engineers—if that sample base were based simply on bachelors degree holders, then only 1 in 5 have a degree in engineering, math, or computer science or the hard sciences, natural sciences or physical sciences.

The point here—the bottom line is here, in order to get sample cases, you have to have very large samples or to get a significant number of sample cases you have to have very large samples because many of your cases are simply not going to be useful in random sampling. This makes surveying very expensive—very expensive to get good sample bases of scientists and engineers.

How flexible is the S&E work force? I attach a summary of the report I did to the Division of Science Resource Studies entitled quality and qualifications in the market for scientists and engineers. This report shows that there is some evidence of fungibility in filling S&E jobs, however, there is typically a cost in terms of lost productivity in use of personnel who do not have direct training in their field of employment. Also, there appear to be career penalties, in terms of earnings, for mobility of various kinds. When individuals shift firms or shift occupations or are out of the labor force for a while, there are career penalties in terms of their earnings. Thus, while there is evidence of fungibility, it is not fungibility without limits and costs.

What we need for better models and projections is more data and better data. The CNSTAT Committee that reviewed SRS's scientific and personnel data system found it wanting in many regards—I served for two years on this committee. SRS staff, whose idea it was to commission this study in the first place, have been both receptive and responsive to the recommendations. I believe that SRS staff have done a professional job in redesign work given financial constraints.

The financial constraints are severe. We cannot hope to have good estimates of the characteristics and behaviors of S&E workers without very large samples. This is particularly true if we want to learn—as you seem to want to learn, as well you should—more about women, minorities, and foreign nationals. My fear is that we will fall back into our old ways, thinking that we have arrived when we have not. I attach and invite you to read the report of the CNSTAT-STPDS subcommittee on goals, which I chaired. We are far from attainment of this vision. Because of financial constraints, I believe that SRS's redesign effort will fall short of providing the informational inputs we need to construct better models. The system will be better, but it will still be lacking in many respects. The CNSTAT-STPDS effort and the NSF-SRS response have been very heavy on glasnost and light on perestroika. We need a lot

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more new thinking. Shortness of time and resources has prevented much attention to how things might be done differently.

There has been criticism of the SRS over the years and especially of late. Few sing its praises. I would like to conclude by singing a note or two. Much of what we know about S&E labor markets is in consequence of the STPDS. There is no substitute for the information that they provide. In a paper I have reviewed the content of the principal personnel survey instrument and find it laudable in many regards. Data from that effort has been extremely valuable in appraising the ability and costs to S&E workers in shifting jobs. That data set has also provided significant inputs for modeling the supply system. There is a long way to go, but let us not forget what has been accomplished.

Thank you.

[The prepared statement of Dr. Dauffenbach follows.]

TESTIMONY ON ISSUES RELATED TO SCIENCE AND ENGINEERING PERSONNEL

to the

Subcommittee on Science
Hearing on Scientific and Engineering Manpower
Rick Boucher, Chairman

U.S. House of Representatives
Committee on Science, Space, and Technology
Suite 2320 Rayburn House Office Building
Washington, DC 20518

by

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July 31, 1991

Biographical Sketch of Robert C. Dauffenbach

Robert C. Dauffenbach, Professor of Economics and Business Administration and Director, Center for Economic and Management Research, College of Business Administration, University of Oklahoma. Dr. Dauffenbach received his B.A. and M.A. degrees from Wichita State University and his Ph.D. from the University of Illinois. He served on the faculties of Wayne State University and the University of Illinois prior to coming to Oklahoma. He joined the faculty at Oklahoma State University in 1977 and served as Director, Office of Business and Economic Research, 1985-1990. He has recently assumed duties as Director, Center for Economic and Management Research, University of Oklahoma.

The Center for Economic and Management Research publishes the monthly *Oklahoma Business Bulletin* and annual *Statistical Abstract of Oklahoma*. CEMR is a storehouse of information on the Oklahoma economy. Staff of CEMR have made numerous and significant contributions to public policy research in Oklahoma. The ORIGINS on-line economic development data base is operated through CEMR.

Dr. Dauffenbach's principal training is in human resource economics and he has received extensive funding of his research on scientific and technical personnel from the National Science Foundation. He has served on a study panels of the National Academy of Sciences that investigated science and engineering personnel research and data needs for the 1990's. He has recently served on the Biomedical and Behavioral Scientists Personnel study panel as well as on a National Academy of Engineering panel investigating adaptability and mobility of engineers. He is author or co-author of articles appearing in *Industrial and Labor Relations Review, Journal of Economics and Business, Journal of Economic Development, Journal of Labor Research* and *International Journal of Manpower*. He is co-author of *The Engineering Degree Conferral Process: Analysis, Monitoring, and Projections* and *Projections of Supply of Scientists and Engineers to Meet Defense and Non-Defense Requirements*, reports to the National Science Foundation.

He is a member of the American Economic Association, Southern Economic Association, Mid-West Economic Association, Western Economic Association and the National Association of Business Economists.

I am grateful for the opportunity to appear before the Subcommittee on Science to discuss science and engineering (S&E) personnel issues. There are many issues that we face as a nation regarding this very small component of the work force. In all likelihood, the competitive success of this nation rests on its ability to cultivate science and engineering enterprise. Faced with problems in science and math education in our public schools, fewer young people in the college-age cohort, an increasing dominance of the women and minorities in the work force (who have not been traditional sources of supply in almost all science and engineering fields), dramatic growth in the share of U.S. Ph.D's awarded to foreign nationals, and pressures internationally in R&D performance, our concern is not surprising.

But, just how concerned should we be? We obviously need data and analysis to appraise the extent to which our concerns are real and require direct action. I have been asked to comment on:

A. Uncertainties and problems associated with estimating demand and measuring supply of scientists and engineers;

B. Size of this work force, distribution of skills across technical specialities, and levels of training required;

C. Value of simulations and models in estimating S&E supply and demand;

D. Value of demographic changes as a predictor of future supply;

E. Actions that could result in more accurate projections; and,

F. Quality differentials associated with use of marginally qualified personnel.

This is a tall order, but I will attempt to provide some insights in the short time available to me.

I have been engaged in research on scientists and engineering labor markets since 1976. During that time I have worked on development of demand and supply projection models, have researched various issues relating to the flexibility of S&E personnel, have served for two years on the CNSTAT committee that produced the report Surveying the Nation's Scientists and Engineers, served on several study panels of the National Academy of Sciences and National Academy of Engineering, and provided at various times advice and guidance to the Division of Science Resource Studies. I have also provided written input to a review on supply/demand balance in the 1990s for the forthcoming biennial Science Indicators report. This section is under review.

Obviously, I believe in economic modeling or I wouldn't have engaged in it for so long. Obviously, too, there are many uncertainties and problems in trying to predict the future. Who knows what the level and distribution of real output will

be among the nation's 500-odd detailed industries in the year 2000 and beyond? Who knows what the productivity trends will be for various categories of labor inputs? Who knows how many foreign nationals who receive U.S. Ph.D's will return home in the 1990s?

Despite these uncertainties, there is great value in models and simulations. Their value lies in the wealth of alternative futures that can be processed through them. While we cannot predict the future, we can look at alternative futures. We need not confine ourselves to one vision of the future. Also, simulations get the assumptions out on paper. They set the foundations for debates on the probable future course of events. The features that models embody also can convey a great deal about how markets function. And, if we don't do simulations, we are not going to get better at them.

I attach to this testimony a brief review of the supply/demand models currently in operation in the Division of Science Resource Studies. These summary materials are still somewhat technical. Still, a quick reading will reveal the key features that supply/demand models attempt to incorporate. In the supply model, basic demographic trends play a very small role. Research from a variety of quarters supports this view.

There are a few comments I would like to make on issues related to the size of this work force and fungibility. First, the small size of the S&E work force makes for special problems. Approximately only four in 100 employed persons in the U.S. work force is a scientist or engineer. This makes for special problems in data gathering. Because of their small share of the work force, it is very costly to sample such individuals. Also because of their small share, it is necessary to rely on special schemes to identify these people (such as relying on occupational codes in the decennial census for preliminary identification of S&E personnel) and survey their characteristics. Because we need to rely on such sampling schemes, we miss those who have S&E training but are working in non-S&E jobs either by choice or temporarily. We miss learning about the ability of S&E trained personnel, not working in S&E occupations, to return to S&E employment. We are in a *Catch 22* that little can be done about. Smallness also thwarts the ability to learn very much about subpopulations, such as women and minorities. The small size of the S&E population, thus, creates many problems and makes surveying expensive.

How flexible is the S&E work force? I attach a summary of a report to the Division of Science Resource Studies (SRS) entitled "Quality and Qualifications in the Market for Scientists and Engineers." This report shows that there is some evidence of fungibility in filling S&E jobs. However, there is typically a cost in terms of lost productivity in use of personnel who do not have direct training in their field of employment. Also, retention rates in S&E employment are very low for S&E trained personnel. Only about one-half of those who received bachelor's degrees in engineering now work anywhere in science and engineering jobs. In addition, this is the highest rate. For other S&E fields, the retention rates are much lower. S&E trained personnel are, thus, outwardly flexible to jobs beyond the S&E occupational domains. Yet within S&E

employment domains, it matters to have the proper training. Also, there appear to be career penalties in terms of earnings for mobility of various types. Thus, while there is evidence of fungibility, it is not fungibility without limits and costs.

What we need for better models and projections is more data and better data. The CNSTAT committee on which I served that reviewed SRS's Scientific and Technical Personnel Data System (STPDS) found it wanting in many regards. SRS staff, whose idea it was to commission the study in the first place, have been both receptive and responsive to the recommendations. I believe that SRS staff have done a professional job in the redesign work, given financial constraints.

The financial constraints are severe. As stated above, the small size of this key component of the work force presents many problems. We cannot hope to have good estimates of the characteristics and behaviors of S&E workers without very large samples. This is particularly true if we want to learn more about women, minorities, and foreign nationals. My fear is that we will fall back into our old ways, thinking that we have arrived when we have not. I attach and invite you to read the report of the CNSTAT-STPDS Subcommittee on Goals of the STPDS, which I chaired. We are far from attainment of this vision. Because of financial constraints, I believe that SRS's redesign effort will fall short of providing the informational inputs we need. The system will be better, but it will still be lacking in many respects. The CNSTAT-STPDS effort and the NSF-SRS response have been heavy on *glasnost* and light on *perestroika*. We need a lot more new thinking. Shortness of time and resources has prevented much attention to how things might be done differently.

There has been criticism of the SRS over the years and especially of late. Few sing its praises. I would like to conclude by singing a note or two. Much of what we know about S&E labor markets is in consequence of the STPDS. There is no substitute for the information that they provide. In a paper I have reviewed the content of the principal personnel survey instrument and find it laudable in many regards. Data from that effort has been extremely valuable in appraising . the ability and costs to S&E workers in shifting jobs. That data set has also provided significant inputs for modeling the supply system. There is a long way to go, but let us not forget what has been accomplished.

NSF-SRS In-House Demand/Supply Models for Scientists and Engineers

Demand Models

Currently housed in NSF's Division of Science Resource Studies are both demand and supply forecasting models. The input-output based demand forecasting model was contracted from Data Resources, Inc. Figure A. illustrates the functioning of this model. The DRI U.S. Quarterly Macro Model is used to generate 53 categories or sectors of final demands (shown in Table I.). Through a final demand bridge, these sectoral demands are translated into industry final demands. Through use of a 92-sector version of DRI's interindustry input-output inverse matrix, the industry final demands are translated into industry total demands. The employment model, which accounts for productivity growth in employment/output ratios, translates industry output to employment per industry, per time period. Industry employment levels are then appropriately multiplied by an occupational employment distribution matrix (occupational model) to produce occupational employment levels. Appropriate summation of the resulting product matrix yields occupational employment per time period. 51 occupational categories are included in the model with special detail in the S&E employment domains.

Demand-side input-output models suffer from their ties to large-scale models of occupational employment. S&E occupations represent only about four or five percent of total occupational employment that such models typically treat. Large-scale models may pay insufficient attention to the special nature of science and engineering demands. For example, gross labor productivity by industry is a component of these models in the form of aggregate output-to-employment ratios. These ratios include all personnel levels, white- and blue-collar. While other adjustments are possible in such models, say, through changes in occupational model coefficients, to account for differential occupational productivity growth rates, such adjustments are rather ad hoc. In recognition that the peculiarities an special factors associated with S&Es may be given insufficient attention through such aggregate mechanisms, NSF's Division of Science Resource Studies has contracted with DRI to provide a special R&D matrix component to the input-output modeling approach. This new component has yet to receive significant use and is sorely in need of evaluation and validation. Evaluations of existing models need to be performed and questions need to be raised on how such models can be more closely attuned to the peculiarities of S&E labor markets.

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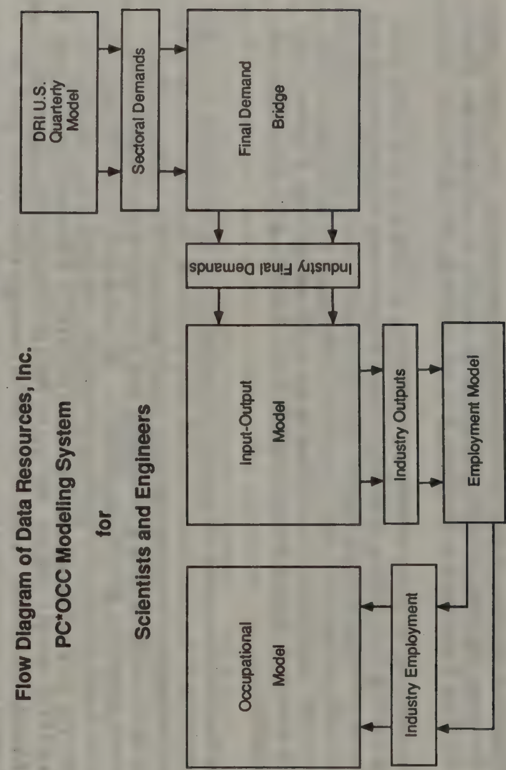


Supply Models

On the supply-side, NSF is now in possession of a new projection model. The new version of the supply projection model builds on the research of Dauffenbach and Fiorito. The underlying philosophy that has guided the construction of this new model is the same. Supply is seen as largely driven by demand and responds to shifts in demand and excess demand in various components of the model. The model recognizes that not all jobs in science and engineering (S&E) are held by science and engineering graduates. The reverse statement also holds. Not all S&E graduates choose careers that are directly tied to their formal educational training. Furthermore, for many of those S&E graduates who work in S&E occupations, degree field and job category do not necessarily match[1]. Systematic accounting of such real world features of S&E labor market behavior patterns is central to successful simulation of supply.[2]

While the new model borrows heavily from Dauffenbach and Fiorito's earlier work, it is distinct in many manifestations. First, the model has been simplified, which allow the model to be constructed and housed on a PC. The model is now functional on three *Microsoft Excel™* spreadsheets. This enables the user to readily process alternative scenarios and test the sensitivity of the model to changes in parameters. The existence of the model in spreadsheet form also enables the components of the model and their interactions to be seen clearly. This opens the way for improved understanding of the concepts, operations, and interactions in the model. It should also make it possible to more readily add additional components to the model and to incorporate alternative assumptions.

Second, the model handles the problem of accounting for experienced worker behavior, the *bête noire* of previous modeling attempts, in a more straightforward manner. The concept of degree-retention time spectrums in S&E employment, called *retention curves* is developed and implemented in the model. Some discussion of this concept is warranted. At a given time, a part of S&E total employment is composed of, say, baccalaureate mechanical engineering graduates, not all of whom are working as mechanical engineers. For the sake of argument, assume that B.S. mechanical engineering graduates employed in any S&E occupation from degree conferrals in year x number 2,000. Suppose also that

[1]Differences between degree field and occupation, such as an electrical engineering trained individual working as a mechanical engineer, are referred to as *field mobility*.
[2]See R. Dauffenbach, "Quality and Qualifications in the Market for Scientists and Engineers," Report to the National Science Foundation, for statistics on degree-field and degree-level distributions in S&E occupations and the salary implications on field and occupational mobility.

there were 5,000 B.S. mechanical engineering graduates in year x. The S&E retention rate for this degree/level category would be 40 percent. In a similar manner, the retention rates could be computed for all graduating classes, forming a time-spectrum of retentions of mechanical engineering B.S. degree recipients. That time-spectrum of retentions would be expected to be initially high and then die-off as alternative careers are undertaken or labor market attrition and retirement takes place. The retention curves, then, measure the participation of S&E graduates in S&E employment. NSF data from the postcensal surveys was used to estimate these retention spectra.

It is natural to expect that the retention curves will be higher for master's degree recipients than bachelor's, and higher for Ph.D's then master's. In part, master's retention curves will be higher because many who hold master's degrees in a given field also hold bachelor's degrees in the same field. This tends to suppress baccalaureate retention curves.

These retention curves can be estimated econometrically for the various degree fields and degree levels, thereby smoothing somewhat the random fluctuations obtained in sample data. These curves can also be moved forward in time and applied to future expected degrees. Thereby, these curves can be used to project future retentions of S&E degree recipients in S&E employment. It is distinctly possible that the retention curves are not constant. In the supply simulations, it is important to incorporate this potential in the model making it possible for the entire retention curve for a given degree category to shift up or down in response to excess demand.

A third way in which the new model is distinct is in the treatment of field mobility. A large number of individuals who hold engineering degrees work as computer scientists, and vice versa. One can construct, through sample data, a matrix that translates field/level of degree into field of S&E employment (occupation). Such a matrix is called the Degree/Occupation matrix and it is easy to convert such a matrix into probability coefficients for a given degree/level category across occupations. The problem is that such a matrix is measured at a point in time and is not likely to remain constant through time. A review of a matrix constructed from 1982 data reveals, for example, a considerable amount of field mobility from various categories of engineering to the occupation of mining and petroleum engineering. This result is probably not as pronounced today. It is unlikely that the coefficients remain fixed. Rather, that they are responsive to excess demand conditions. The new model allows these field mobility coefficients to fluctuate in response to excess demand.

A fourth distinction of the new model is that mechanisms are made available to the user to test the implications of alternative rates of enrichment of S&E employment stocks. All S&E workers do not hold S&E degrees as their highest degree. The computer science employment field is the most obvious example of this phenomenon. Such a result is typical of newly emerging fields. However, with time, credentialism takes hold and universities respond to rising demands on the part of students. The model specifically allows for enrichment by enabling the user to control the rate at which the proportions of S&E employments who hold S&E degrees increases over time. Enrichment operates through adjustments to demand to arrive at that component of occupational demand that is filled by S&E trained personnel.

As described above, the model incorporates a variety of supply adjustment mechanisms. Changes in S&E job shares stimulate or suppress degree production. Excess demand causes retention curves to shift and field-mobility coefficients to change. With the variety of adjustment mechanisms in the model, bottom-line supply/demand comparisons tend towards equality. This is, of course, the way in which the markets operate. In the final analysis, the employment level that firms seek matches the number who seek employment. It is necessary to examine a variety of measures of labor market conditions before assertions of shortages or surpluses are made. Thus, in the model we have to look at more than the final bottom-line of supply/demand balance to discern the stresses and strains that the system may have been subjected to for signs of shortages and surpluses. The new model allows for such assessments to be made. Indeed, in a model with such a proliferation of adjustment mechanisms, it is absolutely necessary to engage in review of changes in parameters in the system for a complete accounting of system stresses and strains.

Large changes in degree production in individual fields are signs of system stress because it may be difficult for universities to accommodate large scale changes. Dramatic changes in field-mobility coefficients are, as well, a sign of stress as are large shifts in retention curves. Of course, differentials on the bottom-line present evidence of stress, as well. It is only in combination that the signals from the model generate a picture of shortages or surpluses. I would argue that this is not unlike the need for review of various measures of supply/demand balance in appraisals of the current status of S&E labor markets. This is a fifth way in which the new model differs from the old. In the old model, more attention was given to bottom-line supply/demand comparisons.

The model is divided into three spreadsheets, simply designated for purposes of this discussion as Spreadsheets I, II, III, incorporating the following components:

I. Degree Projections and S&E Employment Retentions Components
II. Degree/Occupation Raw Data Adjustments and Enrichment Components
III. Field-Mobility and Final Supply Computations Components

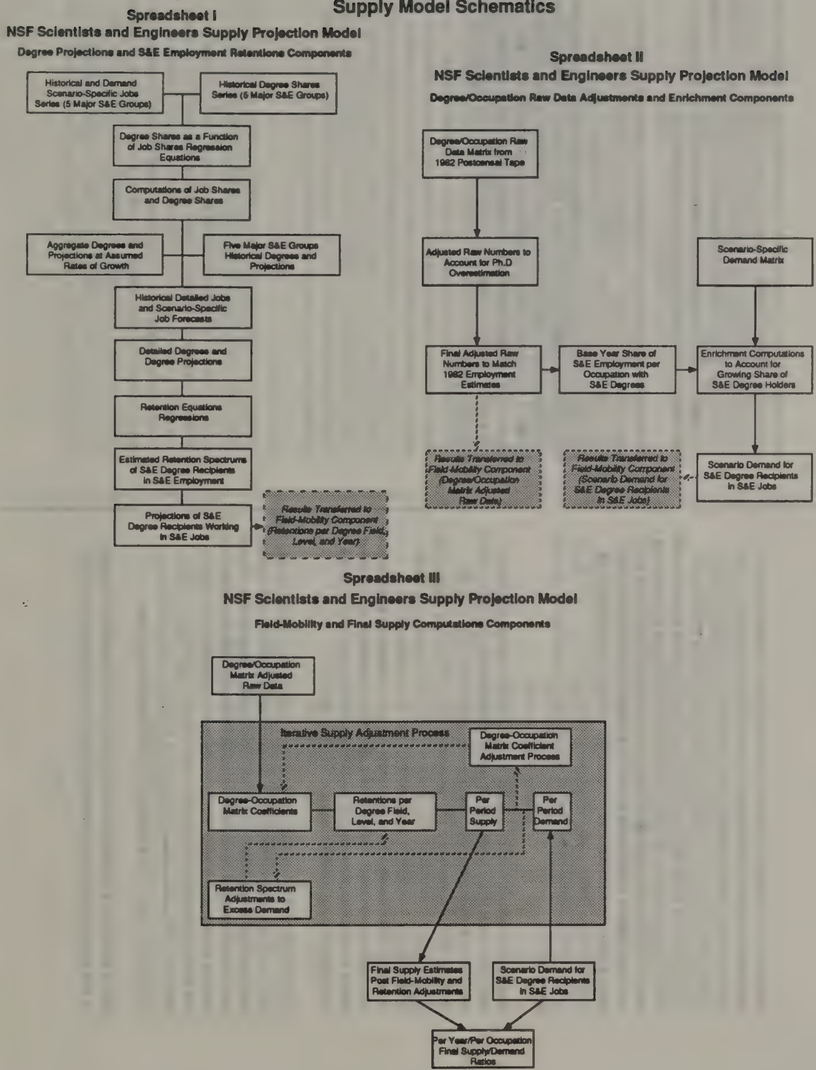
The purpose of Spreadsheet I is to provide degree projections and estimates of S&E degreed personnel who are employed in S&E occupations (retentions). Schematics of the three spreadsheets are presented on the next page.

Degrees are projected using time-varying job-shares coefficients obtained from seemingly unrelated regression (SUR) estimates. Five major S&E groups (Engineering, Math/Computer, Biological, Physical, and Social Science) and three degree levels (bachelor's, master's, and Ph.D.s) are used. Separate SUR analysis is performed on each degree level. The estimated equations are utilized in conjunction with the demand scenario job projections to forecast degree shares. Using aggregate degree production at the bachelor's, master's, and Ph.D. levels, the degree shares are transformed into numbers of degrees for each of the five major groups and three levels. Historical detailed jobs and detailed job forecasts are used with historical detailed degrees to allocate group degree production into detailed degree production.

Regressions estimating the varying shares of degree recipients from various graduating classes who are employed in S&E jobs are used to compute retention curves. Finally, the retention curves are moved ahead through time to produce projections of S&E degree recipients working in S&E jobs. The resulting projections are transferred to Spreadsheet III.

Spreadsheet II executes some adjustments to the raw data that form the degree/occupation matrix of field mobility. This matrix captures the reality that personnel with degree x, even though they work in an S&E job, do not necessarily work in field x. Adjustments to the raw numbers were made necessary because the matrix overpredicts aggregate Ph.D. employment. The matrix is finally adjusted so that the rows and columns sum to the aggregate estimated employment of S&E graduates in S&E jobs. The resulting matrix is transferred to Spreadsheet III.

Figure B.
Supply Model Schematics



Spreadsheet II also includes the enrichment component. This component was added in recognition that the share of S&E employment made up of S&E graduates has, over time, tended to increase. This component provides a means for the user to specify the rate at which enrichment occurs. The process incorporated into the model for enrichment rate adjustments affords greater elasticity to lower rates. That is, lower rates are more upwardly flexible than are higher rates. A rate at the 60 percent level might rise to 62 percent while a rate at the 90 percent level might increase only to 90.5 percent. The closer to unity is the rate, the less elastic is the enrichment response. It is important to note, as the schematic suggests, that enrichment adjustments are adjustments to demand, reflecting the natural tendency for shares of S&E employment who have S&E degrees to rise over time. Results of application of enrichment rates to the basic scenario-specific demands are transferred to Spreadsheet III.

Spreadsheet III contains, then, three input matrices from the other two spreadsheets: (1) Degree/Occupation Matrix Adjusted Raw Data; (2) Retentions per Degree Field, Level, and Year; and, (3) Scenario Demand for S&E Degree Recipients in S&E Jobs. All of the iterative computations necessary to produce the final estimates of supply per occupation per year are done in this spreadsheet. The model is calibrated in such a manner as to equate initial supply and demand values. It is important to note the full meaning of this adjustment. If shortages are known to exist in the base year, it is likely that shortages exist in the final year, even though the bottom-line supply/demand comparisons may still reveal equality in supply/demand outcomes. Consequently, evaluations need to be made in the context of general supply/demand conditions in the base year.

In the schematic for Spreadsheet III, the shaded region denotes those component blocks that are involved in the iterative processing. Retention spectrums may rise or fall and field mobility coefficients may increase or decrease in consequence of excess demand. The user is in control of parameters that determine the number of iteration cycles and the extent of the responses to excess demand within each cycle. The user could, as well, elect to turn-off field-mobility or retention rate adjustments. Such an election might be made in order to find out what the implications are of using the fixed 1982 field-mobility coefficients on future supply. Other interesting simulations can be performed in like manner.

Once an iteration cycle is complete, per period supply values are transferred for storage to the final supply estimates block. Once processing for all years is complete, the user can

view the full range of supply/demand ratios for each of the individual occupations. It is necessary to evaluate more than just the final supply/demand ratios in order to appraise future labor market conditions. Parameters can be chosen in such a manner that whatever shortage or surplus exists is spread evenly across all fields. This can be done by allowing a large number of cycles in the iterative processing and a large degree of responsiveness of field-mobility coefficients and retention curves to excess demand.

Obviously, there is little information in such a result that shows equality in shortages or surpluses across all occupations that are equivalent to the overall S&E balance. Even pushed to these limits, there is still considerable information present in the body of coefficients that make up the model. For example, one can examine the extent to which field-mobility coefficients had to rise in order to yield the bottom-line outcomes. One can check to see how much and which retention curves were forced upward by excess demand conditions. One can check the reasonableness of degree projections, which, after all, reflect demand for degrees rather than the institutional capacity in higher education to meet those demands. Through such means, more robust examinations of shortage/surplus potentials are possible.

Summary

Quality and Qualifications in the Market for Scientists and Engineers

Final Report to the
Division of Science Resource Studies
National Science Foundation
NSF-SRS-8511331

by

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Understanding the degree of flexibility in the labor force is important for analysis of many important issues that need to be addressed today in planning for the needs of tomorrow. In the occupational domain of scientists and engineers (S&E), that need for understanding is paramount. It is arguable that no other occupational domain is more crucial to the present and future competitiveness of the U.S. economy. And yet, the U.S. economy immediately faces the potential of diminishing supply as a consequence of shrinking youth cohorts. Numerous competitive advantages have been lost to foreign competitors in recent years. Without close attention and appropriate action, should action be required, the *research and development* competitive advantage could be lost to the U.S., as well.

Flexibility can be measured in a variety of ways, such as by the ability of individuals trained in given disciplines to attain career success in alternative occupations; by the rates of mobility among firms, occupations, and regions of the country; by the time and resource costs associated with retraining; and so on. The willingness and ability of individuals trained in one field-of-study but working in alternative occupations would seem to be a primary measure of flexibility in the economy. In this sense, anyway, the extent of flexibility among scientist and engineering educated personnel would seem quite large. The Survey of Income and Program Participation (SIPP) provides national labor force evidence on education/occupation correspondence. While this evidence is highly aggregated and is, given the relative small sample base for the SIPP surveys, subject to large sample variation, it is practically the only evidence available. The education/occupation correspondence shares for bachelor's and higher degrees holders who are employed in S&E occupations are as follows:

S&E Major Degree Field	Yield to S&E Employment
Engineering/computing	46.3%
Math/statistics	24.9%
Agriculture/forestry	15.4%
Biology	19.7%
Physical/earth science	34.7%
Psychology	17.1%
Economics	15.7%
Social sciences	5.9%

The largest of these numbers, 46.3% for engineers, is surprisingly small. Note that this number reflects all S&E employment, not just simply engineering employment (which, of course, dominates this category). The next highest value is for physical and earth sciences at slightly more than one-third. Social science discipline yields are particularly low. Evidently, individuals trained as scientists and engineers who find something other than science and engineering to do with their occupational lives predominate. Unfortunately, there is no knowledge of the extent to which such individuals are willing and able to undertake S&E jobs, i.e., the rate of backflows. It is apparent, however, that among S&E graduates the yield to S&E employment is quite low.

A study by Dauffenbach (1989) presents an analysis of various flexibility issues in science and engineering labor markets. Analysis of the correspondence between occupation and education is seen in this study as a primary vehicle for appraisal of flexibility in labor markets. Dauffenbach provides several cross - tabulations of detailed occupation by field-of-study for science and engineering occupations using NSF's 1982 postcensal survey data. A major finding is that while detailed field-of-study is a good predictor of occupational pursuit, the amount of variance is surprisingly high.

Such prevalence of non-exact-correspondence between occupation and education can be taken as evidence of flexibility in the S&E labor market. Dauffenbach hypothesizes, however, that such flexibility is not without attendant costs in the form of diminished productivity. Presumably, if there are productivity differences between workers who are apparently credentialed and workers who are otherwise credentialed, these differences should show up, systematically, in salaries. Thus, he undertakes an extensive analysis of salary differentials by applying the statistical methodology of multiple regression analysis to the aforementioned NSF survey data.

Systematic salary differentials are identified in this investigation and these differentials, in general, support the notion that there are quality differentials that result from non-alignment of degree field and occupational pursuit. In addition, because of the variety of other factors that need to be held constant in order to have an unbiased assessment of the impact of occupation/education

correspondence on salaries, the regression results provide a general assessment of the various factors on salary differentials, such as race, sex, primary work activity, industry, occupation, and professional work experience. Also, because in the 1982 postcensal survey certain questions pertaining to mobility were asked, it is possible to investigate the impact of inter-firm and inter-occupational changes on earnings.

Dauffenbach provides separate regression results for each of the major domains of S&E employment: Engineering, Biological Sciences, Math/Computer, Physical Sciences, and Social Sciences. He concentrates on detailed categories of field-of-study and occupation in his analysis and explores the correspondence between field-of-study and occupation on three levels.

First, there is the exact match level in which an individual is working in an occupation that corresponds exactly with his or her field-of-study, such as a mechanical engineer holding a highest degree from the mechanical engineering field. Second, there is the associated-field level of correspondence, such as a mechanical engineer working as an aeronautical engineer. Third, there is the non-associated level, such as an individual with a highest degree in education working as an engineer. Of course, there could well be differences among major degree fields. Physical science graduates would be expected to be more readily interchanged for engineers than, say, business school graduates. Consequently, non-associated fields were divided into several major fields-of-study, including health, education, business, and all other, in addition to the major science fields. After substantial investigation it was decided to use 35 distinct degree fields, which were mapped into 40 S&E occupations. These categories represent the numerically significant fields and occupations in the NSF postcensal survey.

In the five sets of regressions provided by Dauffenbach, a basic point of interest is the extent to which individuals appear to be working in fields not directly associated with their detailed major field-of-study. The table below summarizes these results.

Degree Field Shares by Field of Employment
(in percent)

Field-of-Study	Occupational Field of Employment: Engineering	Math & Computer	Physical Science	Biological Science	Social Science
Exact Match	54.9	21.6	71.1	61.3	68.4
Engineering	25.1	11.0	4.8	0.8	1.0
Math & Computer	3.0	23.0	1.9	0.3	1.2
Physical Science	5.0	5.2	8.2	4.2	0.4
Biological Science	1.2	3.4	7.4	26.1	1.3
Social Science	1.3	8.4	1.9	1.5	10.5
Education	1.5	5.6	1.5	2.4	3.2
Health	0.1	0.4	0.6	0.5	0.3
Business	4.6	13.0	0.9	0.5	4.9
All Other	3.3	8.4	1.7	2.4	8.8

These results are interpreted in the following manner. Among all of the nearly 20,000 observations of employed engineers, about 55 percent had an exact match between their detailed employment field and their detailed degree field of their highest degree earned. Another 25.1 percent of the employed engineers had an engineering degree, but their degree field did not match their employment field. This leaves a residual of about 20 percent with a degree in an non-associated field. For engineering, the most prominent of these non - associated fields was physical science, followed closely by business degrees. Other results are read in a similar manner. Note the very low ratio of exact matches for the math and computer employment field, owing largely to the newness of this employment field. Note also that individuals with their highest degree in engineering represent sizable proportions of the math and computer and the physical science employment fields.

Of primary interest is the impact on earnings differentials associated with not having an exact match or having a highest degree in a non-associated field-of -

study. If, in fact, there are real productivity differentials associated with individuals who do not match in terms of degree field and employment field, these differentials should be revealed in terms of what employers are willing to pay such persons. The results from the regression analysis support such a hypothesis, as summarized in the table below.

Regression Estimates of Earnings Differentials
(in percent)

Field-of-Study	Occupational Field of Employment: Engineering	Math & Computer	Physical Science	Biological Science	Social Science
Exact Match	10.04*	7.27*	16.42*	0.67	9.19*
Engineering	9.87*	7.76*	18.58*	15.72*	16.84*
Math & Computer	9.93*	8.51*	21.61*	6.35	10.62
Physical Science	5.64*	5.97*	12.04*	8.93	18.24
Biological Science	0.81	-0.21	5.79	-1.50	-12.46
Social Science	1.83	-0.19	0.78	1.48	1.74
Education	-5.03*	-2.67	4.90	-4.28	-8.91
Health	3.91	3.81	12.25	9.40	-59.86*
Business	3.81*	2.83	23.2*	16.51	6.66
All Other	---	---	---	---	---

* Indicates statistical significance at the five percent or better level.

The coefficients are read relative to the salary associated with the "all other" field-of-study, which is the reference group in the regression analyses. Thus, we see that an exact match in the engineering employment field pays about a 10 percent differential above those who have a degree in the "all other" field. But, having a non-exact match, but still having an engineering degree pays almost as much, a 9.87 percent differential. Note also that having a degree in math/computer and working as an engineer also pays a handsome differential of 9.93 percent. Yet, having a highest degree in biology, physical science,

social science, education, health, or business pays somewhat less. The asterisk says that the coefficient is statistically significant at conventional levels.

In the math/computer domain, the coefficient for the associated field (same general field, but not an exact match) is actually higher than the exact-match coefficient. Engineering graduates earn about the same and physical science graduates, slightly less. Other fields of study are somewhat lower. Business graduates are a large contributor to this employment field. They earn 4.0 to 5.0 percent less than engineers working as math/computer specialists.

A total of 75 percent of those working in the physical sciences have physical science degrees. In this employment domain, individuals with biological science degrees are the most frequent other contributor to this employment field. They earn significantly less, about 7.0 to 11.0 percent less. Engineers, another significant contributor, earn about the same amount, if not a little higher than the exact-match, Dauffenbach found. Such differentials are not statistically significant, however.

Also of interest in these results is the finding that for all of the major S&E employment fields, those who have engineering degrees earn as much or more than those who have exact matches with their employment field. This results seems especially significant in regard to flexibility of engineers. However, as noted previously, engineers represent a sizable proportion of only the math/computer and physical science employment categories. Still, the biological and social sciences are large employment fields and even a one percent composition of engineer is not an insignificant number.

Dauffenbach's results also provide information on the extent of mobility of various types: change in employer, in occupation, and in responsibilities. The following table provides these gross mobility rates for the major S&E employment fields, 1976-1982.

Estimates of Mobility Rates 1976-1982
(in percent)

	Occupational Field of Employment				
Type of Change	Engineering	Math & Computer	Physical Science	Biological Science	Social Science
Employer	21.99	27.50	23.22	19.34	23.66
Occupation	10.65	16.99	11.32	10.13	12.16
Respon-sibities	32.32	36.15	28.63	28.51	26.29

Change in responsibilities appears to be rather frequent among the S&E categories and about 1 in 4 or 5 changed employer within the six years. Occupational mobility is substantially lower. Those working in the math/computer employment field were the most likely to be mobile occupationally. 10-12 percent occupational mobility is more common. These mobility figures are derived from retrospective questions. That is, in the 1982 survey, respondents were asked how their jobs have changed from the 1976 date. Mobility results tend to be substantially higher when tabulated from longitudinal data, a results that is most likely a consequence of coding error.

These findings from Dauffenbach's study allow us to place some bounds on the extent of mobility, its character, and earnings consequences. The results imply that there is a fairly high degree of flexibility among engineers, math/computer specialists, and physical scientists. This finding is validated by the magnitudes of individuals working in these employment fields who have their highest degree in one of the other fields, and by the fact that pay differentials are essentially nil among these degree fields within each respective employment field. Other fields, especially business disciplines, contribute significantly at times, but in general have substantially lower pay differentials. When these results are coupled with the evidence that the majority of S&E degree holders do not work anywhere in science or engineering, the extent of flexibility is large, indeed. A major gap in our knowledge at present is the extent to which such individuals are both willing and able to return to S&E career pursuits. This is a knowledge gap in great need of being closed.

STPDS GOALS

INTERIM DRAFT REPORT

OF THE

WORKING GROUP ON GOALS

Charge to Working Group

The subcommittee was asked to reflect on goals, objectives, and issues of content pertinent to the Scientific and Technical Personnel Data System (STPDS). The main responsibility of the subcommittee was to identify the guiding principles, the philosophical underpinnings of the STPDS, that could serve as the foundation for effective construction of the data system. Minimal regard, initially, was to be given to resource constraints on the system. In phase, the subcommittee was asked to examine broad implications for design and the means to achievement of objectives of the system that naturally follow from identified goals.

Identified Goals

The working group discussed goals at an August 27, 1987 meeting in Washington, D.C. The group agreed to the following general goals, presented here in order of relative importance:

I. Satisfy federally mandated reporting requirements for timely data through accurate and efficient sample surveying;

II. Provide detailed profiles of the nation's scientists and engineers in terms of their numbers, qualifications, employment patterns, utilization, and personal characteristics;

III. Foster improved policy analysis and support the planning processes of government, academic, and business institutions;

IV. Provide a research base for improved modeling of S/E labor markets and of flows into, out of, and within the S/E labor force that can pinpoint trouble spots and provide early warnings of future problems;

V. Stimulate interdisciplinary research on S/E personnel in academic communities; and

VI. Generate accurate and timely information on the current status of markets for S/E personnel.

A proposed seventh goal, to service the career planning process for individual students and educational institutions, was not adopted because such activities are broadly within the purview of the Department of Labor and because achievement of the goals would automatically provide significant material for such activities. Additional discussion of the goals and issues that emanate from the goals is given below.

Design Implications and Means to Goals Achievement

The subcommittee believes that many design implications naturally follow as a consequence of the goals statement. Many of these implications are elaborations on themes that have been developing in plenary sessions and in various working groups.

1. An educational focus should be adopted as the primary sampling frame for the postcensal surveys;

2. The in-scope algorithm should be discontinued in favor of imaginative and more direct job-content means of S&E community membership identification in addition to educational background;

3. Two-tier survey methods should be considered in order to increase academic research interest in the data system, provide a proving ground to test new questions and procedures, and, in general, to enable much more extensive examination of work technology, organization and utilization issues; this system would administer (1) shorter questionnaires to large samples to get counts, and (2) longer questionnaires on training, utilization, and other topics to smaller samples to obtain information about S&E worker and work relationships;

4. In terms of relative emphasis on core questions, those features that facilitate research on labor force dynamics, flexibility, and supply modeling should receive special attention;

5. Expansion of NSF-DSRS staff is necessary to give much more attention to analysis and, on a continuous basis, to explore, enhance, and test survey content and methodology;

6. It should be recognized that some issues cannot be easily addressed within the scope of the system: immigrants, foreign national labor market entry patterns, current market assessments, etc. There is a need to find efficient tie-ins to other data systems to maximize the S&E informational content for public policy purposes;

7. Specific attention needs to be given to concerns for longitudinal biases and to more efficient longitudinal sampling that may be assisted by such aids as showing previous responses in new survey rounds;

8. The nature of public policy mechanisms that can be put into effect when problems arise needs to be examined and system responses to such policies need delineation; and,

9. Direct marketing of the need for an expanded system and reliance on all of the leverage generated by this NRC study panel will be necessary in order to convey to the outside world the importance of this data effort and to garner the resources necessary;

Additional discussion of the design implications and means of achieving system goals is given below.

Conclusion

NSF-DSRS has inherited, quite fortuitously yet appropriately, the responsibility for provision of human resources information onthe driving force of the U.S. economy: scientists and engineers. The world is falling in its direction. The accelerated pace of technical change, lost U.S. competitiveness, declining college cohort sizes, increased reliance on foreign nationals, and a variety of other factors and features of U.S. economic terrain point to a growing demand for information on scientific and engineering resources.

A number of "fixes" can be identified for the current data system and need to be instituted. But there is a need to extend current system activities beyond the scope of present budget allocations.

NSF-DSRS can have a great deal of leverage in obtaining the funding to improve the data system. They have a director of NSF who is greatly interested in S&E human resource issues who has already demonstrated a willingness and capacity for leadership in such regards. And, they have us. We can greatly extend their leverage through the findings and pronouncements of this panel, should we choose to do so. Let us so choose.

GOALS--D ISCUSSION

Suppositions

The goals rest on a series of suppositions. These suppositions, we believe, help to set the philosophical tone and to underscore the importance of the work we are engaged in.

- That the U.S. economy is catapulting towards an increasingly technical society
- That the component of the labor force that will play the largest role in new directions is the S&E
- That this component of the labor force will receive increasing emphasis and research attention
- That NSF's DSRS conducts the largest and most robust survey system for monitoring this component
- That NSF's DSRS will continue to be the lead agency for collection and dissemination of information on this component
- That in examining the data system there is a definite need to anticipate future research and public policy needs
- That the information base as it presently exists is largely inadequate for addressing many issues pertinent to the future
- That NSF is seeking guidance on how to optimally extend the data system

- That major redirection and increases in funding will be necessary to achieve an adequate system

Increasing international competition has presented an entirely different world to us, one vastly not contemplated 20, even 10 years ago. The threat of foreign competition forces upon us the necessity to innovate and become more productive. Swift application of new technology will be necessary if we are to succeed in retaining a base of manufacturing employment in the U.S., in sustaining growth, and in producing a rate of productivity advance to support high and rising standards of living in other sectors of our economy. The component of the labor force that will play the largest role in development and implementation of that technology is the S&E labor pool. This runaway pace of technological advance will necessitate a greater policy focus and research emphasis on issues related to S&E personnel. There is already developing a field of management sciences called *management of technology* that is receiving its growth impulses from an expanding recognition of what future concerns will be. Clearly, we need to get our data act together to meet the challenges that lie ahead.

NSF's DSRS, which conducts the largest and most robust survey system for monitoring the S&E labor pool, possesses the legislative mandate and will continue to be the lead agency for collection and dissemination of information on this important category of human resources. Thus, it is altogether fitting that an attempt be made to anticipate policy and research emphasis that this category of human resources will receive in the years ahead. Opportunities lost now, given the major resources being devoted to examination of the system at this time and which is not likely to be duplicated soon, may be lost forever.

In comparison to the uses it could serve and the issues that need attention, the information base as it presently exists is wholly inadequate. Robust examinations, such as the *America at Work* survey proposal provide evidence for this contention. NSF-DSRS-SAS is seeking guidance on how to optimally extend the data system, but, it is fair to say that this is not a pressing concern of the division. Because of budget constraints, these calls for assistance are faint whispers, rather than shouts. It will require a major reallocation of survey expenditures and additional increases in funding to achieve a data system that has the potential to make a real difference. There is a need to move beyond the pure technical considerations of how to do effective and efficient counting of the S&E population. We need to be leaders in a campaign to substantially upgrade the policy content and research applicability of the data system. Radical surgery is necessary and is called for here; yet,

such changes can be accomplished while preserving a necessary consistency in the data series.

Sources and References

Other calls for such changes in the data system are in evidence. The Report and Recommendations of the Working Group on the Scientific and Technical Personnel Data System (December 22, 1986) states that the group "feels strongly that both analytic work and some new data collection initiatives are important if SRS is to continue to provide useful data to inform policy and planning officials." (p. 1) This report notes that DSRS "needs to put greater emphasis on understanding the dynamics of supply and demand for S/E personnel in its data collection and analysis efforts." (p.2) Field mobility, flows into and out of the population, and flows between sectors are mentioned. Special periodic surveys of individuals in critical or emerging fields and technologies are called for. Evaluation of major taxonomies, population definitions, survey sampling procedures, employer surveys, and greater attention to stimulation of research activity are identified domains in need of investigation. Thus, there is a blossoming recognition that more, much more, needs to be done to construct a data system that will serve our future research and policy making needs.

Many subcommittee members addressed goals issues in prepared statements that were very useful to the group. Of course, we all have had the stimulating experience of participation in previous sessions and in related working groups. There were, in addition, Ms. Citro's ubiquitous and detailed notes to fall back on. In addition Ms. Citro provided a copy of a proposal for a survey entitled *America at Work* that stimulated thought and discussion.

Review of the *America at Work* Survey Objectives

An outline review of the *America at Work* discussion paper is provided because it contains a potential blueprint for conduct of certain classes of S&E surveys, because it is quite robust in its cataloging of research issues and subject areas, and because it has helps to better formulate just what it is that we are talking about. Indeed, in many of its manifestations, it appears to be almost uniformly adaptable to the S&E labor pool. The authors are downright insightful, innovative, and anticipatory in their approach. And, because a broad range of social science researchers were involved in this project, one would think that adoption of important elements of the strategy the report describes for the S&E data system would lead to a high demand for the resulting data sets.

The report is most innovative in its pursuit of organizational data, the key informants and descriptives of employing organizations. The report well recognizes the role of organizations in generating differences between jobs in such domains as worker productivity and innovation, worker well-being and satisfaction, and work force behaviors such as absenteeism and quitting. Within organization differences can exist as well. It is interesting to note that organizational factors are key facets of the emerging business/engineering research domain, management of technology.

It is also interesting to note that the report does not call for a massive sample base: Only 3,000 employees are called for in a nationally representative sample. The report also calls for a national employer survey, but here again the sample size is small at 200 organizations.

An outline review follows and in this review the comprehensive nature of this proposed survey should be evident. Information subject areas for employees and employers are listed first, followed by a list of research areas addressed as a result of a previous survey of this type, and lastly, a list of research issues yet to be addressed. Review of these subject heading should help the reader understand just how robust such survey instruments can be.

- Information on nature of labor force and of work
  - Job rewards
    - remuneration
      - hourly wages
      - earnings
      - bonuses
      - fringe benefits
    - challenging work
    - good co-workers
    - work environment
    - trade-offs among alternative states
  - Task and work organization characteristics
    - elements of job assignment
    - tools employed, technologies utilized
    - skills and abilities
    - extent of contact with people
    - nature and extent of supervision
    - autonomy
    - substantive complexity
    - organization of work
      - level of job
      - work group extent and character
    - changes and trends in technology utilization
    - employee position in authority structure
    - job ladder potentials
  - Part-time and temporary employment

  - Subjective perceptions of work and attitudes
    - measures of job satisfaction
    - commitment to work
    - commitment to employing organization
    - ratings of relative importance of various conditions of employment
    - due process
    - adequacy of income and fringe benefits
    - pressures of job from pace or content
    - general satisfaction with working conditions
    - distributive justice--rewards fairly apportioned
    - job evaluation procedures
    - technology integration
    - career ladders and advancement potential
  - Household economics
    - dual career families
    - community correlates
      - education: primary, secondary, university
      - health
      - recreation
      - transportation
      - other social infrastructure
  - Occupational health and safety
    - types of dangers and hazards
    - perceived probability of being injured on the job
    - job pressures
    - kinds of physical conditions
  - Employment stability and job change
    - absenteeism
    - changes in worker productivity
    - feelings about job security
  - Union membership and worker representation
  - Job/employment histories
    - current job and occupation
    - occupation five years ago
    - occupations held prior to present employer
    - career ladders
    - types of jobs and occupations held with the present employer
    - past employment/labor force statuses
    - starting wage

- Information on Organization and Work Places
  - Ecological information
    - local unemployment rates
    - population size
    - age, race and sex distribution
    - public infrastructure
  - Organization
    - basic business characteristics
    - demographic characteristics of organization's labor force
    - employment patterns
    - compensation structure
      - wage and salary scales
      - distribution of employees within brackets

        - extent of movement between pay brackets
- job families
    - job classification and personnel management system
        - Job qualifications
        - job descriptions
    - presence of job ladders and internal labor markets
    - expected career trajectories
    - association of jobs with power, prestige and privilege
- benefits
- employment scheduling
- employment training
- technology
    - full descriptions of technologies employed
    - consequences of new technologies, particularly computerization
    - matching employees skill levels with their jobs
    - consequences on organization of work
    - pace of technical change
- work restructuring
    - Sharing of decision making authority
- labor relations
- formal structural and economic characteristics
    - span of control
    - number of ranks
    - number of sections and departments
    - formalization and centralization of authority
    - administrative intensity
- organization performance
    - extent of profit
    - market share
    - priorities given to competitive strategies
    - rate of growth
    - quality
    - innovation

- Research Issues Addressed
    - Job satisfaction
    - Earnings/income inequality
    - Work-related problems
    - Labor force behavior
    - Work and family
    - Attitudes towards unions
    - Task characteristics
    - Work commitment and work values

- Research Issues not Addressed
    - Use of employer's past job histories
    - Transportation to and from work
    - Effects of automation
    - Experiences with employment agencies
    - Employer's interference in personal matters
    - Suggestions made to employers
    - Impacts of organizational/contextual aspects of employment situation

Categorization of the Issues

The above list is informative, large, and robust. We do not propose that it be adopted in its entirety, but only that we put this information to best use in our quest for improvements in the S&E data system. The *America at Work* survey proposal did help to clarify and classify the issues that lie before us. We present a list of issues related to content and conduct of the survey, in approximate rank order of importance. There is, obviously, some subjectivity that comes through construction of these categories and through placement of an individual issue in one category or another. It was surprising just how many issues fell into the domain of organizational issues.

We have arrived at six categories of issues, each of which contains several elements:

- Issues related to population measurement
    - Appropriate taxonomies of S&E occupations
    - Reduction of inter-survey sampling variation
    - Methods for effective and efficient determination of population pools
    - Methods for accurate interpolation of population counts in non-survey years
    - Optimal of sample size determination relative to human resource groups of more pressing policy concern
    - Optimal sample size determination for women and minorities
    - Strengths and weaknesses of alternative means of specifying initial sample base from decennial census

- Issues related to labor market behaviors and dynamics
    - Predominant dimensions of labor supply functions
    - Dynamic responses to shortages and surpluses
    - Career pattern behaviors
    - Use of S&E trained personnel in non-S&E occupations
    - Curriculum choice/labor market interactions
    - Flexibility of the S&E labor force
    - Interplay of skills and knowledge between S&E jobs
    - Flows of S&E personnel among firms, occupations, industries, and areas of national public policy concern

- Issues related to current assessments and future needs
    - Alternative means for appraisal of current and future supply/demand balances
    - Adequacy of information sources for sophisticated model building
    - Emerging fields and technologies
    - Consistency in taxonomies from various statistical sources
    - Adequacy of methodologies for forecasting future needs
    - Adequacy of methodologies for determining future supplies
    - Interplay of supply/demand forces and incorporation into models

- Issues related to organizational deployment and effectiveness
  - Utilization of S&E workers
  - Use of technology on the job
  - Additional training: nature, objectives, and costs
  - Distribution of skills in execution of R&D
  - Job families and career ladders
  - Interactions and interdependencies of S&E and non-S&E vocations
  - Organizational practices towards S&E personnel
  - Organizational structures: work group size, hierarchies and authority relationships
  - Organizational variation in S&E personnel practices
  - Innovation and its relationship to S&E personnel deployment

- Issues related to policy and institutional dynamics
  - Policy instruments available to affect S&E labor market outcomes
  - Federal and state policy towards S&E labor markets
  - Higher education responsiveness to labor market signals
  - Federal support of university R&D

- Issues related to serving various user populations
  - Effectiveness of alternative methods for determining user population needs
  - Institutional planners and policy makers needs
  - Usefulness of various means for disseminating information
  - Mechanisms for servicing the career planning function

Discussion of Design and Goals Achievement Means

Given the frequently expressed concerns about the policy content, modeling enhancement potential of the data system, one might well wonder why the *issues related to population measurement* received the highest rank. Make no mistake, the measurement problems are real and difficult to resolve. We can never hope to press forward with improved assessments of current and future labor market condition, for example, until we are agreed as to who and how to count. Nevertheless, there is, ultimately, little to be learned from counting because, presumably, a given growth path of the economy could be achieved with a varying combination of S&E population size, organizational practice, and institutional policy. In essence, counting matters and matters greatly, but it is only a first step on the path towards a more complete understanding of the functioning of these labor markets. But, because it is a first step, in fact the first step, counting is at the top of the list.

In regard to broad implications for design, we believe that a focus on educational credentials is appropriate and can be instrumentalized in a manner that avoids the technical difficulties that have emerged in the conduct of previous surveys. The subcommittee's own deliberations support the growing consensus from previous panel meetings and panel

member statements that an educational focus should be used as the primary sampling base for the STPDS. Such a focus would, we believe, help clear the waters, has greater policy relevance in terms of available public policy levers, and would provide major assistance in accomplishing major system goals and objectives. Various evidence has been offered to the full panel in support of a move to such a sample base including CPS, SDR, and postcensal tabulations. Dauffenbach's tabulations from the previous Current Population Surveys are in support of three tendencies: (1) a large proportion of the labor force in the various S&E fields already have college educations; (2) the trend is upward, as well as can be discerned from data with such high sample variation; and, (3) there is a marked increase in the percentage with higher education among younger workers in comparison to their counterparts in the same occupation. These tendencies are true for the engineering fields, as well. The proportion of engineers who have higher education is in correspondence with the science fields, although the proportion who have advanced degrees is, evidently and as expected, lower. We find that the CPS data are in support of using an educational focus for the design of STPDS.

Additional tabulations from the postcensal are reported here in Tables I-II from the 1982 postcensal, experienced, sample. Both weighted and unweighted tabulations for occupation by field of highest degree are presented. No restrictions are made for current employment, age, sex, NSF in-scopeness, etc. To be included, however, the respondent must have earned a bachelor's or higher degree. We see a very high percentage of respondents who report an occupation as engineer as having engineering as their highest degree. The percentages are significantly higher when a broader swath of having an S&E degree is cut. It may well be the case that business and other degrees that are close substitutes for science and engineering are localized (say, operations research), rather than general in nature. A large scale postcard survey would bring out such information.

Reliance on other survey methods may well be necessary in order to obtain information on groups that are members of S&E job categories with very low probability. For example, individuals with business degrees working as engineers. In order to efficiently obtain a sample of such S&E work force members, it may be necessary to use an occupational basis. Whatever methods are chosen, they should be chosen with an objective of minimizing the horrendous stratum 11 problems that have damaged the present system.

On the role of the screening algorithm, the subcommittee prefers to dump it in favor of a primary if not total reliance on educational credentials. This is not to say that elements of flexibility, substitution, and cross-elasticities of supply do not need attention. They do

need systematic attention. But, too much confusion results from the application of the screening algorithm and too much potential for error is generated through its use. Why muddy the waters with this one? There are more direct and forthright means of addressing this problem.

The subcommittee favors adoption of a two-tier system of survey methods in line with recommendations contained in the *America at Work* survey proposal. The paper closes with additional discussion on this matter.

In deliberations, substantial attention was focused on the need for questions that reflect on education, training, retraining, job technology, job mobility and retirements. In terms of relative emphasis on core questions, the subcommittee seems biased towards those features that facilitate research on labor force dynamics, flexibility, and supply modeling. This may seem somewhat of a narrow view, but the relevance to policy concerns is direct.

Looking at what could be done to provide information on a cost effective basis, we call upon a passage from Albert Rees "Information Networks in Labor Market," American Economic Review, Vol. 56, May 1966, which explains the difference between extensive and intensive margin search.

> The search for information in any market has both an extensive and an intensive margin. A buyer can search at the extensive margin by getting a quotation from one more seller. He can search at the intensive margin by getting additional information concerning an offer already received. Where the goods and services sold are highly standardized, the extensive margin is the more important; when there is great variation in quality, the intensive margin moves to the forefront. This point can be illustrated by considering the markets for new and used cars. Since there is relatively little variation in the quality of new cars of the same make and model and since the costs of variation are reduced by factory guarantees, the extensive margin of search is the important one. A rational buyer will get quotations from additional dealers until the probable reduction in price from one additional quotation is less than the cost of obtaining it.
>
> In used cars of the same make, model, and year much of the variation in asking prices reflects differences in the condition of the cars, and this calls for a substantial change in the strategy of the rational buyer. He will invest less in obtaining large numbers of offers and much more in examining each car.

This example has some limited relevance to our inquiry. That is to say that STPDS data collection and design efforts should have both extensive and intensive margins. It is appropriate to cast the problem of obtaining good counts and providing some of the more basic information on labor market behaviors and work histories as an extensive-margin problem: A more restricted set of key information on a large sample base. S&E workers in

these large samples are treated, not as homogeneous exactly, but as capable of being categorized in a relatively restricted set of occupations. We need a lot of quotes, so to speak, in order to come up with good estimates of the various S&E populations. This is an extensive margin type survey.

Obtaining the more robust information that would be of use to researchers and policy makers and that would explore more in-depth some of the questions relating to technology and organizational arrangements is an intensive-margin problem. In this domain of inquiry, one would be concerned with acquiring a sizable amount of qualitative information on a relatively small population base. The *America at Work* Survey proposal is cast on an intensive-margin base: large amounts of information on a relatively small sample base. This is how more intensive inquiry becomes possible and affordable in the context of present budget allocations. The larger the sample size, the better in any given inquiry. Yet, to conduct research of a high quality and statistical significance, it is simply not necessary to have tens of thousands of data points.

Just what particular items should be present in the two types of surveys is a subject for discussion and debate. Nevertheless, we believe that by separating the two functions, it becomes possible to expand the domains of inquiry, stimulate use, and not go too far over budget.

On the question of available resources, the answer is simple: **get more!** The level of expenditure is simply too miniscule in relation to the overriding importance that the information will have. Put simply, design, construction, and operation of the STPDS data base is not the place to scrimp. We know that resources are limited and that DSRS is very much constrained in this regard. But, limited too may be our future if we do not invest in the information sources needed to guide public policy and facilitate research. NSF-DSRS simply needs more people analyzing the outputs of the system (wherein, problems will become more quickly identified and more readily resolved) and in examining and testing assessing survey alternatives. In-house expertise on survey methodology would seem a mandatory beginning. The future is now. There is no time for delay. And, what this paper shows, if anything, is the large amount of work that lies ahead just to obtain a reasonably functioning system.

Mr. BOUCHER. Thank you, Dr. Dauffenbach.
Mr. Ellis?

STATEMENT OF RICHARD A. ELLIS, DIRECTOR OF MANPOWER STUDIES, AMERICAN ASSOCIATION OF ENGINEERING SOCIETIES, WASHINGTON, D.C.

Mr. ELLIS. Thank you, Mr. Chairman and members of the Subcommittee.

I am the Director of Manpower Studies for the American Association of Engineering Societies. My job involves the production of research for the Association's Engineering Manpower Commission. The Commission, or EMC, is over 40 years old. Its members are drawn from engineering societies, industry, universities, and the government—all of them are volunteers.

EMC is the main source of data in the United States today on the enrollment and degree production of engineers, and it is also a key source of information on the compensation of engineers. The Commission will hold a major conference in September on supply and demand. It has also created a new task force on the engineering work force, which will work for the next several years on the issues that concern this subcommittee today. The Chair and Vice Chair of that task force, Mr. Fred Schulz and Colonel J.D. Strong are here today.

I should note my prepared statement has been cleared through the leadership of the Association of Engineering Societies and the Manpower Commission and is considered representative of the views of those organizations and the member societies that comprise them. I will not attempt to go through the details of the prepared statement which does respond, I think, in some detail to a wide range of the questions posed in the memo that announced this hearing. I'll only hit some highlights and summarize our position here in this oral review, at the moment.

If we take the purpose of these hearings as addressing, as Congressman Boucher has put it, uncertainties and problems associated with estimates of supply and demand for scientists and engineers, I should say the Manpower Commission gets requests on a daily basis for information on those matters from journalists, corporate and government planners, scholars, prospective students and their parents. I would like to give the subcommittee some sense of what we have to say to those people, not just what we are saying to you, but what we are saying to the general public.

First, current estimates of the supply of scientists and engineers are not providing the details of specialty, experience, or region that most users need. There are gross inconsistencies between the different Federal sources of data. Of the available estimates, those in the Federal Bureau of Labor Statistics are the most useful. And as the memo that announced these hearings indicates, NSF's data on the technical work force is not very credible.

Secondly, on the demand side, the employment projections done every two years in the BLS Occupational Outlook Handbook are, in our view, the only useful forecasts that we have. This is not to say that they are adequate. They are merely all that is available. In assessed work on projected shortfalls of scientists and engineers

has not survived serious reviews of its assumptions and methods. This is not to say that there will not be shortages, it only says that we don't know very much.

To fix this situation, we endorse the reforms that have been suggested by the National Academy of Sciences, but we fear that those changes may not be enough. Even if the technical workforce data system was accurate and precise, which it is not, it would still be too slow to keep up with the pace of innovation. It would not provide meaningful levels of detail, and it would remain ignorant of global movements in the location of work places and in the migration of workers.

We are disturbed by the Nation's dependence on primitive systems for its intelligence on such large questions as the availability and utilization of scientists and engineers. The work of these people is critical for success and the attempts of this Nation to deal with major issues of our time like the economy, energy, the environment, transportation, health, and national defense.

An adequate system to track these people must be timely, getting out information before it becomes hopelessly dated. It must be thorough and detailed so that it deals with specific areas where there may be shortages or surpluses—not broadly, but in particular segments of the work force—for we may have simultaneous shortages in one area and surpluses in another. And it must pay attention to the global context of science and engineering activity. This may be asking for a lot, but lesser systems will only mislead us.

Our own experience with the EMC's operations and with Federal operations that generate timely, trustworthy data on economic indicators like inflation and unemployment, suggest to us that a much more swift, detailed, accurate system of intelligence on scientists and engineers is both feasible and affordable. My prepared statement indicates a number of actions that could be taken to move toward those goals including steps that would help to implement the changes in NSF's Scientific and Technical Personnel Data System, as well as some interim moves that could improve our knowledge about these issues while the NSF system is being rebuilt.

AAES, the Association of Engineering Societies and its Manpower Commission, is ready to help in any way that we can to meet these needs. And as first steps, we will spread information from these hearings to industry and to the professional community at the upcoming EMC Conference on Shortages and Surpluses in September,and our task force will be pursuing these matters in detail for some time to come.

I am prepared to field any questions you may have, and we want to thank this subcommittee for its interest in this problem, which we think is a very serious matter.

[The prepared statement of Mr. Ellis follows.]

UNCERTAINTIES AND PROBLEMS ASSOCIATED WITH ESTIMATES OF LABOR MARKET SUPPLY AND DEMAND FOR ENGINEERS AND SCIENTISTS

Statement and Supplementary Materials:

TESTIMONY FOR THE HEARINGS ON SCIENTIFIC AND ENGINEERING MANPOWER

SUBCOMMITTEE ON SCIENCE,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
U. S. HOUSE OF REPRESENTATIVES

July 31, 1991

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UNCERTAINTIES AND PROBLEMS ASSOCIATED WITH ESTIMATES OF LABOR MARKET SUPPLY AND DEMAND FOR ENGINEERS AND SCIENTISTS

The comments below are based on the experience of the Engineering Manpower Commission of the American Association of Engineering Societies. The Commission, or "EMC," is over 40 years old; it is made up of volunteers from engineering societies, industry, universities, and government. EMC is the main source of data in the United States on engineering enrollments and degrees. It is also a major source of information on engineering salaries. The Commission will hold a major conference in September on questions of the supply and demand for engineers. In addition, EMC has formed a new Task Force on the Engineering Workforce that will work for the next several years on these issues. At present the Task Force's work is unfunded and done entirely by volunteers.

I: Critique of Existing Information Systems

EMC receives hundreds of queries every year from journalists, corporate and government planners, scholars, students, and others who need information about the supply and demand for scientists and engineers. Here is what we have to say to these people:

1. *On the supply of scientists and engineers:* Current data on the production of new engineering graduates are provided rapidly, accurately, and in considerable detail by EMC. Similar data on the production of new science graduates are provided more slowly and in less detail (and probably at higher unit costs) by the Department of Education; in addition, thorough coverage of Ph.D. degrees is provided by NSF's Doctoral Records File. Estimates of the numbers of these graduates who go on to become actual engineers or scientists are needed, as are statistics on crossovers between science and engineering, on flows of migrants into and out of the U.S. technical workforce, on movements out of technical work into other kinds of activity, on deaths and retirements, and other flows of workers in and out of the labor pool. Accurate measures of such movements require longitudinal surveys in which specific people are tracked over time. The design of the NSF Scientific and Technical Personnel Data System (STPDS) provides for these types of needs, but the approach has not been adequately implemented (see below).

   In addition to these measures of movements into and out of the workforce, regular enumerations of all scientists and engineers are needed. National data on technical workers are provided by three federal agencies, all of which are assisting EMC's Task Force on the Engineering Workforce. The first of these, the U.S. Census, generates fairly detailed information but is so slow in its production that it is dated before these details are published. The Census has been the only national source of data on occupational distributions at the level of states and cities. Although those statistics have been provided for decades, Census staff advise us that this crucial information will not be generated for 1990.

The second source of national supply-side data on technical workers is the U.S. Bureau of Labor Statistics. We advise callers that the employer-based data on the current workforce in the BLS industry-occupation matrix, updated every two years to produce the *Occupational Outlook Handbook*, is a good count of people employed in industry as engineers and scientists. The matrix statistics are not perfect for these purposes. For example, they cannot separate out people with science or engineering backgrounds who are working in related areas like management or education. Also, there are doubts about the accuracy of the BLS data for some disciplines, an issue that will be explored in more detail by the EMC Task Force.

BLS also generates quarterly current workforce estimates from its Current Population Surveys (CPS). These are similar to the Census in that the statistics are household-based and use self-reported occupations, rather than the employer-reported counts used for the industry-occupation matrix described above. The CPS and Census results are reasonably consistent, so the two efforts are complementary: the availability of CPS data helps to compensate for slow production of the Census, while the Census helps to flesh out the more limited material provided by the CPS. These surveys also provide a way to make rough estimates of the numbers of people who may think of themselves as engineers or scientists but who are regarded by their employers as something else, such as managers.

Combining both BLS sources, it is reasonable to say that in the U.S. today there are roughly 1.5 million people employed as engineers, making this the nation's largest single professional group other than the combined totals of both elementary and secondary school teachers.

The third source of general technical workforce statistics is the lead agency designated by Congress for these matters, the National Science Foundation. NSF has responded to this mandate by combining data from a number of sources, including its doctoral records files, post-Censal surveys, and other gap-filling efforts, using an elaborate statistical model to generate final STPDS estimates of the numbers of scientists and engineers. As the National Academy of Science's Committee on National Statistics concluded (in the report referenced in the announcement of these hearings, *Surveying the Nation's Scientists and Engineers: A Data System for the 1990s*), this system is not providing adequate information.

For example, according to NSF the number of engineers grew by 441,000 people between 1986 and 1988. This is three times the number of new graduates during that period. New degrees are not the only source of new engineers, but discrepancies of this magnitude are not credible. The same data indicated that the most common type of engineer in the U.S. is a mechanical--when for over 20 years graduates in electrical and computer engineering have far outnumbered all other specialties.

2. *On demand for scientists and engineers:* We advise people that the only credible forecast of future demand for engineers in the U.S. is the set of medium-range (10-15 years) employment projections done for the BLS industry-occupation matrix, the same source of information noted above for supply-side statistics. This is not to say that the BLS statistics are adequate; in fact they are not. Most of those who seek supply-demand data for technical professionals need timely information on specific combinations of people with particular specialties, particular levels of experience, in particular geographic locations. Neither supply nor demand data are available in the United States at these levels of specificity (see Item 3 below for further comments).

   NSF is another source of information on demand. For example, the paper "Scientist and Engineer Supply and Demand," done by Larry Leslie and Ronald Oaxaca for NSF's Division of Science Resources Studies in late 1990, is a very good (if perhaps overly pessimistic) state-of-the-art assessment of academic research on this topic. Similarly, the Foundation's Division of Engineering Infrastructure has been a major source of support for the pioneering studies done by the Institute of Economic Analysis at New York University, exploring the use of large-scale input-output models as a way to predict effects of changes in technology on the employment of engineers.

   Although formally unpublished, the series of draft working papers on "shortfalls" of scientists and engineers, predicted for the 21st Century by NSF's Policy Analysis and Research staff, have received a great deal of attention in the media. We have commented on these papers in one of the four EMC *Engineering Manpower Bulletins* attached to this statement ("Prospects for Engineering Manpower"). Our analysis can be summarized as follows: we are not convinced that the NSF/PRA shortfall studies provide credible evidence that there will be future imbalances between supply and demand. This is not to say that shortages of technical workers will not arise. It only says that we do not know very much.

Our remaining comments deal with more specific questions raised by the Subcommittee about these general supply-demand issues.

3. A major weakness of much of the work on supply and demand for technical professionals is that overly broad conclusions tend to be drawn. Findings are presented for all engineers, or all scientists, or both groups together, or they are presented for some subgroup with the implication, either tacit or explicit, that the results are generally applicable. This can be very misleading. The nation can experience *simultaneous* shortages of science and engineering faculty, surpluses of older workers in industry, spot shortages of new graduates in "hot" fields like environmental or manufacturing engineering, and surpluses of graduates in other fields. Little if any objective data exists on the supply/demand mix for all these *subsets* of the technical workforce.

Moreover, when all of these differing situations are mixed together at the aggregated, national level, it is possible for supply and demand to appear to be in balance when in fact they may not be (or vice versa; in either event, the picture one gets is an illusion). The failure to face this fact accounts for the confusion and heated debates that have characterized the literature of supply and demand for technical people. One group shouts "Shortage!" while another screams "Surplus!" In fact, both parties may be right, but they are not talking about the same things.

4. Demographic trends for the U.S. work force are one important determinant of the future supply-demand mix for scientists and engineers. But other factors are also important, including the interest and ability of potential students; the strength of many particular economic sectors as well as the overall health of the entire economy; the scale of the defense budget and of public and private R&D spending; trends in utilization and productivity of technical workers, and in their use of new technologies such as computer-assisted design systems; patterns of migration, which may be influenced by recent legislation; the propensity of multinational organizations to do technical work in other countries; and emerging technologies, which will determine the needs we have for particular kinds of people. Few if any analyses allow for all these factors.

5. Many issues of concern to those seeking data on scientific and technical workers cannot be addressed at all with the existing data. Many examples have already been noted above: we have no regular, trustworthy measurements of the attrition of new graduates to nonscience or nonengineering work, of the movement of established workers into or out of technical careers, of effects of migration into and out of the nation, or of such locally crucial statistics as simple enumerations of the makeup of the technical workforce in particular states and cities. Many other examples can be added. We have no precise understanding of the factors that influence talented youngsters to choose or reject science and engineering careers at either precollege or college levels. There are no national sources for data on the comparative attrition of groups like minorities and women in science or engineering education.

6. The Subcommittee is interested in the specific issue of measurement of losses in the quality and quantity of scientific and engineering output when shortages lead to the substitution of less qualified workers. We doubt that such effects have been common enough to constitute a researchable problem. Both specific surveys and broader inquiries (such as those sponsored in 1989 by the National Academy of Engineering on workforce flexibility) indicate that engineers are fairly adaptable, and price competition in labor markets seems to have been adequate in the past to attract workers to emergent areas of practice (for example, involvement of electrical engineers in the design of computer software).

Policymakers may wonder if insufficiencies of scientific and technical talent may be related to the loss of U.S. domination in such global markets as consumer electronics and the machine tool industry. But we do not think inadequate levels of national engineering skills in these sectors are functions of workforce supply. If real shortages occur, we should see rises in the cost of engineering services. Despite repeated fears of shortages during the last 20 years, the evidence says that the supply of engineers, which has been growing rapidly since the end of World War II, has been adequate to meet demand since the late 1960's, when constant-dollar levels of engineering compensation reached a postwar peak. During the 1980's, there was a brief recovery in the value of pay for some very experienced engineers, but those improvements (which imply temporary extra demand for senior people) did not last. Nor did they extend to the rest of the workforce, probably because unprecedented growth took place in the production of new engineers between 1975 and 1985, when the annual numbers of graduates doubled. EMC's bulletin "Engineering Manpower Trends, 1950-1990," attached, provides additional information.

Instead, we think that losses of U.S. technical domination in many major world markets may be more likely to be a function of choices that employers make as to what markets they wish to pursue, and whether to pursue a market using domestic or foreign technical support. American companies still sell TV sets, but they do not depend only on Americans to design them.

7. Another distinction of interest to the Subcommittee is that of levels of training. The need to distinguish between people with B.S. and Ph.D degrees is noted in the announcement for these hearings; in fact, NSF has long recognized that there are serious needs for data on an even wider range of people, from skilled technicians at the associate degree level to post-doctorates. The Foundation's strong suit has been data on academics at the doctoral level, but good intelligence on all scientific and engineering workers demands much more than this. Engineers comprise the largest portion of the technical work force by far, and although increasing numbers of them are pursuing degrees at the master's level and above, it remains quite feasible for an ambitious person to pursue a career in the profession with a bachelor's degree and reasonable use of the programs of continuing education that are provided by industry, academic institutions, and professional societies.

8. Issues of appropriate methods are raised by the Subcommittee's interest in the value of the use of simulations and models to explore issues of supply and demand for technical workers. Such tools are probably essential, although they cannot do the job alone; they are dependent on their data sources as well as on forecasting assumptions and the general skill and diligence with which these tools are applied. The key to success in these efforts is not the application or rejection of any particular approach, but rather the adoption of generally rigorous practices, irrespective of methodology.

Contrasting examples of simulations and model-building are provided by several of the data sources discussed above. Input-output models are used to generate the BLS industry-occupation matrix, the less successful outputs of the NSF's Scientific and Technical Personnel Data System, and the Institute for Economic Analysis research on relationships between technical innovation and workforce requirements. These illustrations demonstrate how similar methods differ in their ability to generate satisfactory results. The crucial differences are more likely to be those of implementation than any inherent virtues or liabilities in the methods themselves.

9. Four issues of EMC's *Engineering Manpower Bulletin* are attached to this statement. The first, "How Many Engineers" (No. 92, January, 1989), deals in more detail with supply-side questions. The second, "Engineering Manpower Trends, 1950-1990" (No. 101, May, 1990), contains useful general background data on historical movements in supply-demand indicators. The third and fourth issues, "Demand for Engineers: A Review of Current Thinking" (No. 104, September, 1990) and "Prospects for Engineering Manpower" (No. 105, October, 1990) address problems of forecasting potential needs and shortages.

   These publications contain information that bears on some of the puzzles raised in the memorandum announcing these hearings. "How Many Engineers" shows how definitional differences help to explain why NSF's counts of scientists and engineers are so much larger than those from BLS. "Prospects for Engineering Manpower" suggests why the NSF data account for only a fraction of all those people whose highest degrees are in science or engineering fields (among others, many secondary teachers have such degrees). In turn, these observations suggest that many of the problems associated with the issues of supply and demand for technical workers may be traced to poor analysis, presentation, and discussion of the facts, as well as to possible inadequacies of the data base.

There are also serious theoretical and conceptual problems to be overcome in order to deal satisfactorily with issues of supply and demand for scientists and engineers. From the perspective of mainstream economic thought, both "shortages" and "surpluses" of technical workers are nonsensical concepts; equilibrium of supply and demand is assumed. Yet the literature is full of discussions of shortages and surpluses. From a forecasting perspective, prediction of demand for engineers and scientists rests heavily on factors that must themselves be predicted, like the state of key economic sectors. Some observers of this scene, taking note of such problems, have concluded that the issue of assessment of the supply and demand for technical people is simply not one that can be sensibly addressed with the available scientific tools. We do *not* agree with this pessimistic view. While completely satisfactory systems to provide good intelligence for the management of technological growth in the United States may not be developed overnight, there are many cost-effective steps that should be taken now to pursue this goal.

II. A Critique of Proposed Actions

A major focus of these hearings is on responses thus far to the recommendations for improvements in the technical workforce data system made by the National Academy of Science's Committee on National Statistics (*Surveying the Nation's Scientists and Engineers: A Data System for 1990s*, op. cit.). We endorse the conclusions and recommendations of that study. Our reservations are only that we are not sure that the recommendations go far enough in stressing needs for speed and rapid response, much more detailed attention to critical subsets of the workforce, and the importance of the larger global context of science and engineering activity. Even if the existing system for the collection and analysis of data on scientific and technical workers was acceptably accurate and precise, which it is not--

--It would still be too slow to keep up with technical innovation;

--It would not provide meaningful details; and

--It would remain ignorant of movements on the global level in the location of workplaces and the migration of workers.

In an era when pollsters and market researchers report results to their clients overnight, we cannot understand why this nation depends on such primitive systems for its fundamental information on questions like our ability to compete in a multinational, high-technology-based world. Access to an adequate technical workforce will be crucial in determining how well we cope with many of the most difficult issues confronting policymakers today, including economic growth, appropriate development of our cities and countryside, energy, the environment, transportation, and national defense. It is not an exaggeration to say that the well-being of the United States is at stake.

Accordingly, it is understandable that the Congress expects to be able to track not just the general availability of scientists and engineers, but more specific availabilities of people with appropriate specialties, experience, and skills. As the cost engineer Arthur Dershowitz puts it in EMC's bulletin on the state of the art of demand assessments, the critical issue is not so much the overall need for technical workers, but rather advance knowledge of the *nature* of those people who will be in demand. To accomplish this, the reforms currently under consideration are needed, but they may not be sufficient in themselves to generate the information that is required:

--An adequate system must function rapidly so that it keeps up with the development of new technology. Timetables more like those that we use now at EMC are required. We issued detailed reports on over 120,000 U.S. engineering degrees for 1990 in December of last year, and on more than 600,000 students enrolled in the Fall of 1990 in engineering and engineering technology programs by early April of 1991.

47-644 O - 91 - 3

--An adequate data system on scientific and engineering manpower should generate annual reports on both current and projected workforce supply and demand for a whole range of specific subsets of the technical workforce, including assessments for people with differing specialties and levels of training, with various levels of experience, and in differing geographic locations.

--An adequate system must not try to describe scientists and engineers with only single-discipline, simple labels. Most technical workers have multiple skills. Failure to allow for this fact leads to serious under-enumeration of specialists.

--An adequate system will require a more intensive level of longitudinal research, tracking larger post-Censal panels of practitioners at least every other year. This will provide current measurements of flows in and out of the technical workforce, from one specialty to another, from technical activity to management, from active work to retirement, and so on. Beyond its value for policy research, better dissemination and publicity for such a system will also serve as a signal to students and working scientists and engineers that the nation is concerned about their careers--a badly needed incentive, especially for our youth.

--U.S. data should be assessed in the context of information on the world-wide scientific and engineering workforce. When work itself is exported and workers--including U.S. citizens--migrate across national borders, realistic assessments of supply and demand for technical people cannot be made on a purely domestic basis. Indeed, U.S. employers frequently tell EMC that they need better data on the foreign scene. Adequate information on the global technical workforce is not presently available. We will not solve this problem quickly, but we need to start dealing with it right now (one possible approach is suggested below).

These specifications imply a scientific and engineering workforce data system with the following components: use of a regularly maintained model of the entire workforce--the existing BLS matrix might suffice--as the starting point for a more detailed, broader pool of data on technical workers; ongoing rapid-response longitudinal surveys of a series of panels of practitioners, to capture flows in and out of the labor force; a wide range of analytic systems, probably including large-scale input/output models, to handle the large number of detailed policy issues that need attention; an effort to begin the collection of similar kinds of data on a world-wide level; and regular, preferably annual, reports that address meaningful subsets of the population of technical workers as well as the workforce as a whole.

This may be asking for a lot, but lesser systems will not do the job; they will only mislead us.

Is this feasible? We think it is, from the perspective of the capabilities of up-to-date research methods, from the perspective of funding, and from the perspective of the capacity of the federal government to do the job. Our final points address some of these practical considerations. These include suggestions for some interim steps that can help to bridge the gap between where we are now and where we need to be by the turn of the century.

1. *On rapid-response research systems and the ability of the federal government to support them:* Our convictions are based on our own experience. EMC currently operates a research system which provides very thorough, accurate, detailed information on both engineering enrollments and degrees within six months of the events tracked by these annual surveys. In addition, it carries out a large annual study of engineering compensation (data on the salaries of approximately 138,000 engineers in early 1991 was released in several hundred pages of printed reports earlier this month), and it will publish ten bulletins or bulletin-like products this year, including a special report on a pilot survey of men and women engineers, up-to-date analyses of the general statuses of women and minorities in the profession, and work on other topics.

   All this work, from data collection and entry to drafting final written commentaries (to say nothing of such activities as the support of the Commission's internal affairs and participation in meetings like this hearing) is handled by just three full-time workers plus about one half-time equivalent in part-time help. (It must be conceded that one reason why our staff loads are low is that EMC obtains an extraordinary level of involvement and support from its volunteers, who determine the content of all projects, actively assist in obtaining the cooperation of survey respondents, and provide detailed reviews of drafts of all our publications.) The budget for this entire research production operation is well under half a million dollars a year, including allowances for all overheads.

   EMC can be this productive because it is small, private, and automated to a very high degree (the last factor, which is as critical as the others, took over four years, from mid-1985 through 1989, to achieve). In contrast, federal research systems are necessarily ponderous. They must respond to a extremely wide range of interests and require reviews of work throughout a complex hierarchy of authorities. Most such systems are intended to be the ultimate authorities in their domains, and thus they tend to be large in scale, a trait that does not always lend itself to maximal efficiency in research. Federal systems may also be susceptible to the common bureaucratic disease in which programs are carved up into sets of smaller projects that become ends in themselves rather than serving the broader purposes for which they were originally funded.

There are well-known exceptions to this general picture. The federal system routinely generates widely trusted, rapidly generated current data on such matters as the state of the economy. Hence we offer this thought: if the Congress comes to believe that that timely data on the technical workforce is needed as badly as current information on unemployment, or inflation, or housing starts, then the systems that generate those statistics, rather than the more leisurely procedures that have used to generate workforce statistics in the past, should be examined as potential models for NSF's use. There is no reason why data collection on scientists and engineers has to be slow; speed is merely a function of the importance we attach to an activity and the approach one takes to getting the job done. In today's competitive environment, we cannot afford to be slow.

We would also observe that rapid-response research systems need not cost one more dime than the alternatives. Indeed, because such systems demand high efficiency they are often less costly than their more ponderous brethren. For the same reasons, they can also be impressive demonstrations of scientific skill.

We do not mean to suggest that rapid-response data systems are without their risks and drawbacks. One problem such systems may create is the danger of overly hasty analysis. Appropriate correctives and safeguards ought to be built into all research systems, and ideally federal policymakers ought be able to draw on both rapidly generated policy indicators and more considered studies of strategic alternatives.

2. *On the collection of data on the global technical workforce:* There is a tendency to assume that such efforts are too difficult and costly to be worthy of serious consideration. We do not agree.

   An emerging priority of both EMC and the American Association of Engineering Societies is collection of global data. The AAES Board of Governors is especially concerned with the need for better information on the practices and standards that support and inhibit cross-national activities on the part of engineers. EMC has cooperated for several years with efforts to gather cross-national data on engineering workforces by mail, conducted by the World Federation of Engineering Organizations (WFEO; AAES is the U.S. member of this body).

   So far, WFEO's efforts to collect workforce data through voluntary efforts conducted through the mails have not been very successful. Few engineering organizations abroad have the familiarity with local statistical sources that is needed to cooperate with such requests without drawing on expert assistance. On a bilateral basis, EMC shares information with similar operations in such places as Canada and Australia, but more serious projects are going to demand more serious levels of support.

International agencies like USAID, the World Bank, and the UNDP have evolved well-proven approaches to research situations like the collection of global data on technical workers. Centrally coordinated teams of data collectors are created and equipped with consistent, comparable frameworks for the treatment of the varying definitions and conventions of data systems in different nations. These teams are then sent out to work with local counterparts in short (one to two weeks) visits to countries of interest, tapping such sources as national censuses and population registers, which are available in one form or another in virtually every nation. Following these data collection visits, information can be examined and adjusted to generate comparable measures of workforce activity. Additionally, the local counterpart teams in the source nations provide a source of continuing contacts for updating data. These kinds of efforts will not resolve all of the problems of cross-national data collection on scientists and engineers; in particular, they will not deal at all with the complications of movements across national boundaries by both the workforce and the work itself. But one must start somewhere. Projects such as this can begin to build elementary pools of data on world-wide enrollments, degrees, and current aggregate numbers of engineers and scientists. This will go a long way toward clarifying the global context, and will set the stage for further refinements and advances in the information base.

3. *Two Interim Opportunities:* An adequate system to track technical workers cannot be built overnight; it will take years to realize all benefits of the longitudinal components. But there are steps that can be taken to help fill these gaps.

   With the technical assistance of EMC's research staff, the Society of Women Engineers is now converting its periodic "Profile of the Woman Engineer" into a full-scale survey of both men and women practitioners. A pilot test of this project was conducted in 1989-90. Further expansion of the project, to cover both scientists and minorities, is being considered. This ongoing project offers an opportunity to gather interim data and to test new approaches to research on technical professionals.

   During the 1960's, NSF, along with the American Association for the Advancement of Science and others, sponsored a major longitudinal survey of the national college graduating class of 1961. Carried out at the National Opinion Research Center at the University of Chicago, this project created a massive data base covering every aspect of the background and training of those graduates. Now, thirty years later, the NORC respondents are at the peak of their careers. NORC staff advise us that this study can be reopened. Doing so will create an unprecedented opportunity to conduct research on the career histories of mature scientists and engineers, at bargain costs. We urge you to consider taking this step.

In summary: all parties seem to agree that NSF should continue to take the main responsibility for the federal government's efforts to track supply and demand for technical workers. The recent recommendations of the Committee on National Statistics provide a start for the reforms that our data systems require. We are suggesting that Congress ought to consider the merit of going beyond these findings and recommendations, to also insist that NSF create mechanisms to track scientists and engineers that establish new standards for timeliness, detail, and cost efficiency, and which include a recognition that technical activity is increasingly rooted in a multinational, global context. The National Science Foundation ought to be a leader of such efforts. If the government wishes to draw further on EMC's own experience in order to pursue these goals, we will respond as constructively and positively as possible.

ENGINEERING MANPOWER BULLETIN

This 92nd Engineering Manpower Bulletin revives a topic last treated in 1976: the wide discrepancies that exist among various estimates of the number of engineers in the United States. It explains how differences arise in these statistics, and provides some guidance for informed use of the data.

EMC conducts annual surveys of engineering enrollments, degrees and salaries. Inquiries about EMC and its projects are welcome. Contact R. A. Ellis, Director of Manpower Studies, American Association of Engineering Societies, (202) 546-2237.

HOW MANY ENGINEERS?

How many engineers are there in the United States? The corporate executives, researchers and others who contact EMC for information on this seemingly straightforward question are frequently dismayed to learn that there is no corresponding straightforward answer. The most recent government statistics are for 1986. Depending on which set of numbers you use, in that year there could have been as many as 2,634,900 engineers, according to the National Science Foundation (NSF).[1] Or there may have been as few as 1,331,747, according to the Bureau of Labor Statistics' (BLS) Industry-Occupation Matrix.[2] Still other figures can be cited. Can these disparities among the statistics be explained? And can some single estimate of the number of engineers be derived and defended?

WHY IT MATTERS

Over the last few years, leaders in government, industry, and finance have voiced increasing concern about the state of the U.S. economy as it copes with foreign competition in most major areas of production. Underlying the United States' loss of leadership in the manufacture of such varied products as steel, automobiles, ships, and electronics is a weakness in productivity that is perceived as a result of a failure to take full advantage of up-to-date technology. This leads directly to questions about the education and utilization of the supply of engineers, scientists, and technicians, since technological leadership cannot be maintained without an adequate, effectively utilized supply of educated, trained, motivated people.

Manpower appears to have been a forgotten ingredient in attempts to formulate more effective national policies to regain U.S. technological leadership. Those who do pay attention to manpower statistics are worried; they see a growing trend in the direction of inadequate scientific and technical literacy, in an era when mastery of these matters is essential. Technology is sterile if it is not applied; if applied by people without the right knowledge, it is ineffective, even dangerous. Engineers are therefore crucial to the proper utilization of technology and to the ultimate ability of U.S. industry to compete in an international market economy.

With the encouragement of such organizations as the National Academy of Engineering, the National Research Council (NRC) initiated a series of studies[3,4,5] that disclosed serious deficiencies in the availability of data essential to an understanding of engineering manpower problems. These reports were followed by a detailed review of data resources by the NRC Committee on Data Needs for Monitoring Labor-Market Conditions for Engineers.[6] The major conclusion of the latter study group was that existing data bases—principally those maintained by federal government agencies—should be improved to permit their use in formulating and implementing national policies in areas where engineering and related technological manpower resources are a factor. In the words of Robert M. White, president of the National Academy of Engineering, these data are "most important as the United States faces the problems generated by a global economy, a strongly internationalized engineering enterprise, and industrial competitiveness.... Policies need to be based on quantitative, not anecdotal, data".[7] Areas of particular concern were identified as occupational mobility, technical currency, international flows of engineers, and the utilization of women and minority members. In particular, a need was sensed for longitudinal surveys of the career paths of individuals, so that policymakers can obtain more precise information on the flow of people into and out of technical work. "Clearly," White said, "we need decidedly better and more relevant quantitative data if we are to monitor with confidence the dynamics of the engineering component of the nation's technology base and formulate wise national engineering manpower policies."

Given these kinds of affirmations of the need for sound data on the details of engineering manpower, it is not suprising that seekers of information are somewhat disconcerted by anomalies and seeming contradictions in available statistics on such elementary matters as the number of engineers. As noted above, the Bureau of Labor Statistics' Industry-Occupation Matrix indicates that there were about 1.332 million employed engineers in 1986, and that this number may rise to about 1.762 million in the year

2000 (using the BLS middle-ground "moderate" projection). A different BLS data base says that there were already 1.749 million engineers in 1986.[8] To add to the confusion, NSF publications state that there were 2.635 million engineers in 1986; 195,000 of these were not in the labor force, leaving 2.440 million employed. Are these different estimates reporting the same thing? No, they are not. Is this a case of the government's left hand not knowing what the right hand is doing? Perhaps. To unravel this tangle, some background is needed.

HOW DIFFERENT COUNTS ORIGINATE: THE BLS DATA

Surveys conducted by the U. S. Department of Labor's Bureau of Labor Statistics are central to practically all national manpower data estimates. BLS maintains two independent sets of data that provide statistics on the number of employed engineers; the two estimates differ by about 417,000 people. There are good reasons to use more than one set of data, but the practice can confuse users of the statistics. For example, a recent news item[9] noted that the Department of Labor's numbers had caused some controversy in the recent presidential election campaign because of inconsistencies in job data for August 1988, which indicated that employment had increased by either 140,000 "as measured by the department's survey of households" or by 219,000 according to its "survey of business payrolls." These two surveys are the basis for the Labor Department's data on all occupations, including engineers.

The survey of households—the Current Population Survey (CPS)—is based on interviews at about 60,000 locations and is intended to provide broad statistics on employment, broken down by demographic and educational characteristics. The occupational categories used are the same as those used in the decennial census conducted by the U. S. Department of Commerce.

Household data, whether collected by the full census or through a sample survey, relies on the person who happens to be interviewed to accurately describe the occupational status of the household members. The more obvious pitfalls of occupational data collection and classification are well known, and elaborate coding systems are in place to ward off some of the more obvious possible errors, like confusing railroad engineers with other kinds of engineers. Even so, household data probably inflate the numbers of engineers reported, if only because some paraprofessionals who are technicians may prefer to use the more prestigious term "engineer" to describe their jobs.

The BLS payroll survey—the Occupational Employment Survey (OES)—is based on questionnaires mailed to about 240,000 employers. Although the survey form does not pinpoint the educational credentials of the workers reported by these organizations, it does provide a definition of engineering that implies possession of an appropriate college degree: "persons engaged in the practical application of physical laws and principles of engineering for the development and utilization of machines, materials, instruments, processes, and services, including those engaged in research, development, production, technical services, and other positions which require knowledge normally obtained through completion of a 4-year engineering college program." Workers are categorized by their employers according to their current assignments, not by their education and training, so many individuals regarded as engineers by the profession are classified under other headings, such as college faculty, administrators and managers, and sales personnel. This is one reason why the OES data yield conservative estimates, if one is counting all persons with engineering training (as opposed to counting those who happen to be employed in hard-core engineering jobs).

Another reason why the OES numbers will be lower than the CPS numbers is that the employer survey does not cover the self-employed workers who are included in the household study. The BLS states that this "largely accounts for the differences in employment figures between the household and establishment surveys."[10] Perhaps, but not in engineering. In the same publication, BLS provides data that do add the self-employed workers to the OES numbers; this adds in 40,000 engineers, but that accounts for less than a tenth of the difference between the two BLS surveys for the profession. It seems reasonable to suggest that at least a substantial share of the remaining 377,000 disputed workers are people who think of themselves as engineers but who are classed by their employers as managers.

The OES data are the principal source for the low estimate of 1,331,747 engineers cited above. The figure actually comes from a related BLS data base known as the Industry-Occupation Matrix.[11] Updated every two years, the Matrix is especially useful because it includes projections of future employment (for the year 2000, in the current version) in addition to estimates of current employment. The Matrix estimates are presented down to the unit level, but their actual precision is not that fine-cut.

These points help to explain the apparent contradictions between the various BLS estimates of the numbers of employed engineers. The Industry-Occupation Matrix data are bound to be conservative compared to the CPS figures, because the numbers in the Matrix are drawn mainly mainly from OES employer surveys, which exclude the self-employed and which use a comparatively strict approach to define engineers.

HOW DIFFERENT COUNTS ORIGINATE: THE NSF DATA

National Science Foundation (NSF) statistics on engineers are generated by NSF's Scientific and Technical Personnel Data System (STPDS), another large computer-based model that depends on input from three separate sources: the Survey of Science, Social Science, and Engineering Graduates; the Survey of Doctorate Recipients; and the National Survey of Natural and Social Scientists and Engineers. This system was developed in the 1970's to replace the former National Registers of Scientists and Engineers.

The three NSF surveys are conducted biennially. The first consists of a sample of new college graduates; the second is drawn from the Doctorate Records File maintained by the National Research Council on all doctorate holders for the past 42 years; and the third is a sampled population of employed scientists and engineers. The data from the three separate sources are weighted and combined in a complex computer program to produce estimates of the total U. S. population of scientists and engineers.

A basic source of differences between NSF and BLS data on engineers lies in the makeup of the group being counted, i.e., how the two different surveying organizations define the "engineering community." BLS is principally concerned with the entire labor force. It classifies workers across all possible occupations. Its

employment data exclude persons who are retired or otherwise not in the labor force and those serving in the armed forces, as well as unemployed people. Workers are classed in occupational groups on the basis of current job assignments, not by their education or other background.

NSF, on the other hand, is concerned only with enumerating science and engineering workers. Instead of surveying all employment and assigning people to appropriate occupational catagories, NSF attempts to build an estimate of the total stock of potential scientific and technical people. One does not have to be currently working as an engineer to be classed as an engineer. Instead, NSF defines engineers as persons meeting at least two out of these three criteria:

- has earned a degree in engineering (two-year degrees count, if the worker meets the second criterion);
- has been employed in an engineering occupation; and/or
- is professionally self-identified as an engineer on the basis of total education and work experience.

Thus NSF specifically includes engineering managers, sales engineers, and engineering professors in its estimate. It also counts some technicians with two-year associate degrees (who are formally included in the Foundation's definition of the engineering community). It is also possible for persons to be regarded by the profession as engineers (by virtue of their possession of an engineering degree), but to be classed by NSF as scientists (because they are employed in, and regard themselves as members of, such gray-area fields as information and computer science). Similarly, some chemists may have come to think of themselves as chemical engineers, but could still be classed as scientists by NSF. Similar problems of classification affect the BLS surveys. Some ambiguity of this kind is unavoidable, given the overlapping boundaries of science, engineering and technology.

TECHNICAL QUESTIONS

Some of the concerns raised by engineers about the NSF work force numbers entail questions about the technical merit of the studies. For example, can the survey of recent graduates can cover all engineering fields equally well, given that a sample of colleges might miss specialties that are offered only by a few schools? Will employment data collected from the recent graduates reflect their actual utilization, given the propensity of industry to rotate young engineers through a number of jobs shortly after being hired?

NSF's contractor for the survey of recent graduates, the Institute of Survey Research (ISR) at Temple University, uses a stratified multi-stage sampling frame to guarantee coverage of all the major producers of new bachelor-level engineering degrees. This bulletin is not an appropriate vehicle for a full-scale technical review of ISR's sample design. It is clear, however, that NSF and its contractors are aware of the need to pay special attention to smaller subsets of scientific and technical people who are of particular interest. For example, nuclear engineers as well as some other energy-related practitioners are treated with separate sampling strata, in order to assure good coverage for the Department of Energy. There may be sampling weaknesses in the NSF surveys. In particular, there may be a need to provide for special coverage of many emergent specialties, like manufacturing engineering, as well as other smaller subgroups like women chemical engineers or Hispanics in aerospace engineering. But such weaknesses are more likely to be a matter of the limits of available funds and the policy priorities of the sponsors than of defects of method.

With respect to the concern about data on early work experiences of engineers, the studies of recent graduates should yield a wealth of data on the details of both initial and longer-term engineering job assignments. The survey instruments include many items on this topic, and the sampling procedure catches people with a minimum of about a year of experience since graduation; as the postcensal period lengthens, the effects of additional years of experience can be studied. For example, the 1984 survey of recent graduates included data on the classes of 1980, 1982, and 1983.

The survey of doctorate recipients, which is central to NSF's work on most of the scientific work force, provides only minor inputs to profiles of the total engineering population; according to NSF, less than five percent of all engineers hold doctorates. EMC's surveys of engineering salaries yield only slightly higher estimates of the proportion of doctoral-level engineers in industry (6.5 percent). So neither the strengths nor the weaknesses of this data source have much effect on overall statistics for the engineering work force.

The third survey, based on a sample of employed engineers and scientists, raises different technical concerns. This project uses the decennial census as a screen to sample engineers, scientists, and technologists for detailed postcensal studies done on an every-other-year schedule. The difficulty is that the sample represents the population at the time of the original census, not at the time of the follow-up studies; the original sample is tracked from year to year until a new census allows it to be replaced. As with all longitudinal surveys, a portion of the original sample is lost to attrition in each subsequent wave of follow-up questionnaires.

The problem of attrition is that it is not likely to be random. The most common cause of attrition is probably simple refusals by people to cooperate with follow-up waves of the study. If such persons tend to be the busiest ones, that is one threat to the integrity of the sample; if they tend to be those who are not staying in the profession of engineering, that is another. Another source of attrition is inability to keep up with some participants' changes of address, which in turn are strongly associated with job changes; as the sampled group ages, the proportion of retirees is likely to increase while the share of very mobile people is likely to shrink. While some of the more mobile engineers may be people who cannot hold a job, repeated sociological research suggests that most of those who move are very likely to be the more talented and ambitious workers. Thus, attrition in longitudinal surveys is likely to introduce systematic biases into the data, so that it becomes increasingly unrepresentative of the actual engineering population. One possible net effect of all the various biases could be to lose track of significant numbers of people at the "cutting edge" of engineering.

Both NSF and its contractor (in this case, the Bureau of the Census) are aware of the general need to monitor biases of attrition in repeated longitudinal surveys. Some broad checks on the effects of attrition have been made. Thorough reviews of the project files at NSF and at its several contractors would be needed

to determine whether those materials are responsive to the particular threats to the design that have been noted here.

OTHER DIFFICULTIES

A closer look at the breakdown of engineering by fields indicates that the categories reported by BLS and NSF are not completely comparable. The final categories used in reports are actually aggregates of more detailed groupings used in the respective data- gathering questionnaires. NSF uses a minimum of 17 fields and a maximum of 27 in its various surveys; these must then be combined by the computer program into the 11 reported categories. The two BLS surveys also use different breakdowns, ranging from 13 fields in the household (CPS) survey to varying numbers in the payroll (OES) survey. In the latter, the questionnaires are tailored to each industry group. This allows the closer identification of engineering specialties within an industrial sector, but results in groupings that are not consistent from industry to industry, since fields that are identified separately in one industry are lumped under "all other" in other industries. Table 1 shows how fields of engineering are actually described in three of the simple classification systems; potential inconsistencies exist wherever the titles used are not identical.

Difficulties of another kind arise because data for the various surveys are obtained from different types of respondents in every case: company employment managers for the BLS OES survey and the Industry-Occupation Matrix, household members for the BLS Current Population Surveys, and individual engineers for the NSF studies. Without belaboring the point, it is understandable that members of these groups are likely to have entirely different interpretations of questions asked about occupations, and to respond differently to oral interviews or written questionnaires.

TABLE 1

FIELDS OF ENGINEERING AS USED IN DIFFERENT DATA SOURCES

National Science Foundation	Bureau of Labor Statistics: Industry/Occupation Matrix	Current Population Survey
Aeronautical, Aerospace, or Astronautical	Aeronautical and Astronautical	Aerospace
*Agricultural	–	*Agricultural
Chemical	Chemical	Chemical
Civil or Architectural	Civil, incl. Traffic	Civil
*Computer	–	–
Electrical or Electronic	Electrical and Electronics	Electrical and Electronics
*Environmental or Sanitary	–	–
Industrial	Industrial, except Safety	Industrial
*Marine or Naval Architect	–	*Marine and Naval
Mechanical	Mechanical	Mechanical
Metallurgical or Materials	Metallurgists and Metallurgical, Ceramic, Materials Engineers	Metallurgical and Materials
Mining or Geological	Mining, including Mine Safety	Mining
Nuclear	Nuclear	Nuclear
Petroleum	Petroleum	Petroleum
*Sales	–	–
*Systems	–	–
Other Fields	All Other	Engineers, n.e.c.

* Indicates fields aggregated in the major data tables

The scheduling of the different surveys also poses questions as to the timeliness of some of the data. The BLS household survey is conducted on a monthly basis, covering a wide range of different topics over time, while payroll surveys are conducted annually over a three-year cycle, such that not all of the industrial sectors are surveyed each year. Since the matrix program, in which the two sets of BLS data are integrated, is updated biennally, some input data will not be strictly current. NSF conducts some surveys annually, but the major input to the Scientific and Technical Personnel Data System comes from the three biennial surveys described above. In addition to gaps and lags in the data-gathering process, delays in analyzing and publishing the results mean that both the BLS and NSF reports are always at least two or more years out of date. This lag is a serious shortcoming for fast-changing fields like science and engineering.

The dated nature of these surveys is worsened by a problem that affects all attempts to measure evolving disciplines like engineering: it takes time for new specialties to mature into fields that are recognized by their own practitioners as well as by census takers or labor economists. For example, manufacturing is one of the fastest-growing engineering disciplines, one that is of great interest to policymakers, but it is practically impossible to get sound statistics on the profession of manufacturing engineering because its practitioners come from many different backgrounds and are not labeled in a consistent way from one workplace to the next. Most engineering schools do not yet separate the field into a separate department, or label their graduates as "manufacturing engineers." One of the only trustworthy indicators of growth in the field is the expanding membership of the Society of Manufacturing Engineers (SME). More effort is needed to reduce the lag between the emergence of such fields and the ability of bean-counters to provide statistics about them.

RECONCILING THE ESTIMATES

Given the foregoing, several points seem clear. First, large differences between the existing estimates of the numbers of engineers are to be expected, because the different estimates use different definitions of the population to be counted. The BLS Industry-Occupation Matrix is limited to people defined as "engineers" by employing organizations. Data from the BLS Current Population Survey adds in self-employed people and uses self-reported, rather than employer-defined, definitions of who is or is not an engineer, which is less restrictive. The NSF data base adds in many other kinds of people, includes engineers not currently employed in "hardcore" engineering jobs, people with two-year degrees, and engineering educators; the result is a count of the entire stock of engineering-related personnel rather than an estimate of mainstream engineering employment.

Second, concerns about estimates of the engineering work force seem to be especially relevant when one focuses on newer and smaller segments of the profession, such as emergent disciplines or data on women and minorities. These smaller subgroups are precisely the ones of greatest current interest to policymakers and engineering managers. Methods that may be good enough to generate rough estimates of the aggregate number of possible workers may not be nearly good enough to provide accurate data about such key elements in that population.

Third, the work force estimates are subject to the same threats of error that confront all surveys, such as problems of sampling design, attrition in longitudinal data, and unstandardized classification schemes (in this case, inconsistent approaches to the division of engineering into subfields; in fairness, it must be noted that engineering is a decentralized profession in which there are few hard-and-fast rules of classification that apply across all possible disciplines and workplaces). Additional errors may be introduced when the survey data are subjected to further manipulations in computer-based mathematical models.

Given the differences of definition noted above, it is possible to make some rough adjustments to the NSF data that bring them much closer to the estimates of employed engineers provided by the BLS, as follows:

NSF total engineering population	2,634,900
Less those unemployed or outside the labor force	194,800
Less those employed but not in engineering	196,600
Less those whose primary work activity is management	646,100
Less those whose primary work activity is sales	64,500
Less those in the military (other than management)	10,100
Less those teaching in the educational sector	42,100
Less those with only two-year degrees	263,100
Adjusted NSF total	1,217,600
BLS total (Industry and Occupation Matrix)	1,331,747

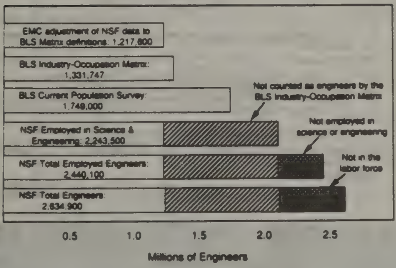
Figure 1 depicts the effect of these adjustments in a graph. Although this procedure brings the NSF and BLS Matrix estimates for the total number of engineering jobs to within about ten percent of each other, the data still exhibit some serious inconsistencies. For one thing, the adjusted NSF total is smaller than the BLS estimate. Since the former data should include the self-employed engineers that we know are missing from the BLS Matrix, one might expect this difference to run in the opposite direction. Of course, our own adjustments draw only on published tabulations and are necessarily primitive. For example, we took out all engineers whose primary work activity is management. Although many such persons might not be judged to be "engineers" in the workaday sense of that word, many others are likely be engaged in the management of engineering projects and clearly should be included in the count. If half of these managers were counted as employed engineers, the adjusted NSF estimate would rise to 1,540,650—almost exactly in the middle of the two BLS figures (the one from the Matrix plus the second estimate from Current Population Surveys; the actual mean estimate of engineering employment that one gets by averaging the two BLS statistics is 1,540,373.5). Such a compromise, based on a simple averaging of the BLS numbers, is appealing for other reasons. It makes some allowance for the apparent stringency of the Matrix data and the likely tendency of the CPS surveys to err on the high side due to self-reported occupational data. The adjustment exercise indicates that a roughly similar result can also be generated using the NSF statistics.

In summary, it is possible to come up with a rough estimate of the number of engineering jobs (defined as work that requires a B.S. in the profession or an equivalent degree), at roughly 1.5 million in 1986, which is at least arguably consistent with the various government data bases.

As might be expected, given the comments above about problems with smaller subsets of the data, the approach of adjusting NSF's data to reach a closer approximation of the BLS results yields much less satisfactory outcomes when it is applied to particular groups of people or engineering disciplines. Serious inconsistencies in subsets of the federal data bases dealing with women and minorities were noted in the previous *Bulletin* in this series (No. 91, "Minorities in Engineering"). In Table 2, adjustments similar to those described earlier are made for ten engineering disciplines plus an eleventh "all other" residual category. Even without making further allowances to count at least a portion of the engineering managers, it is evident that unsettling inconsistencies remain for many of the disciplines, including chemical, mechanical, materials, and mining engineering. In each of these instances, the adjusted NSF total is still substantially larger than the corresponding BLS Matrix figure; additional fiddling with the data for engineering managers and administrators

FIGURE 1

DIFFERENT COUNTS OF ENGINEERS



NOTE. See text for sources and comments on the adjusted data.

TABLE 2

COMPARISON OF DATA SOURCES BY FIELDS OF ENGINEERING

Field	NSF Total	NSF Adjusted**	BLS/CPS	BLS Matrix
Aero/Astro	117,300	56,800	93,000	51,627
Chemical	171,700	79,000	59,000	51,374
Civil	381,400	167,600	233,000	193,151
Electrical	620,700	314,600	550,000	391,529
Industrial	144,900	57,400	203,000	116,409
Mechanical	547,800	257,100	287,000	228,737
Materials/Met.	57,400	28,400	(in "Other")	17,826
Mining	18,900	10,000	(in "Other")	5,228
Nuclear	23,500	13,900	(in "Other")	13,762
Petroleum	33,400	20,600	(in "Other")	19,701
Other	517,900	212,200	324,000	242,403
Total	2,634,900	1,217,600*	1,749,000	1,331,747

*Fields do not add up to total because of rounding.

**"Adjusted" data derived by the author. See text.

will only make these disagreements even worse. Clearly, other differences must exist than those identified above.

WHAT SHOULD BE DONE?

The 1988 National Research Council report on data needs set forth 15 recommendations, three rated as immediate and six as "most important." These are summarized as follows:

- Existing data bases should be continued and enhanced to expand our knowledge of the engineering community.
- Data bases should be made more longitudinal and timely in nature.
- The National Academy of Engineering should hold periodic meetings of data collectors and users to coordinate efforts and address needs arising from changing policy issues.
- Data on engineers should reflect the full scope of the profession and continuing changes in the activities and responsibilities of individual engineers. To this end, the report included a number of specific suggestions for improving the data collection surveys.
- There should be more overlap and cross-correlation among data bases.
- NSF should develop better information on the international flow of engineers.
- NSF should make "periodic cross-tabulations of occupational mobility."
- The NSF surveys should be broadened to investigate mechanisms for maintaining technical currency.
- Employment data bases should include information on levels of technical and supervisory responsibility.

The remaining six recommendations call for special studies involving immigrants, women and minorities in engineering, utilization and technical currency, and newly emerging fields of technology.

All of the committee's suggestions, including those not spelled out above, are useful. For example, the study committee felt that an engineer would be better defined as a person having any one of the following qualifications:

- BS or higher college degree in engineering;
- Membership in a recognized engineering society at a professional level; or
- Registration or licensure by a government agency.

However, the committee appears to have given only superficial attention to the more technical problems of unrepresentative or aging samples. Standardizing definitions of engineering and its specialized fields, expanding questionnaires and data banks to facilitate cross-coordination, and conducting surveys more frequently are all obviously desirable steps, but if the survey samples do not truly represent a cross-section of the engineering population—especially, if they cannot produce reliable data about some of the smaller subsets of people, such as minorities, women, and those in the emerging specialties—then we will merely be trying (to borrow a phrase from economist Herbert A. Simon) to "deal with bad aggregate data by using sophisticated econometric methods." [12]

It is also possible that the econometrics procedures may leave something to be desired. The NSF data are especially dependent on the accuracy and precision of the mathematical model used to manipulate the results of the several component surveys. The actual manipulations performed on the survey data by NSF's model are complex and obscure, as is usually the case when multiple adjustments are carried out on a complex data base with the assistance of a computer. Weights and other parameters must be supplied; some of these may require heroic assumptions. As this is written, a full examination of the NSF personnel data system, done by the Committee on National Statistics at the National Academy of Science, is nearing completion (a final report is anticipated early in 1989). NSF expects that this effort will lead to a major upgrade in its methods for the measurement of the scientific and engineering work force in the 1990's.

—John D. Alden

John Alden retired in 1986 from his position as accreditation director for the Accreditation Board for Engineering and Technology (ABET). From 1965 through 1978, he served as Director of Manpower Studies for the Engineers Joint Council (the predecessor of the American Association of Engineering Societies) and Executive Secretary of the Engineering Manpower Commission. He is the author of many earlier issues of this Bulletin including two previous editions of "How Many Engineers?" He is also an author of several books on naval historical subjects.

Some of the technical commentary in the text on questions of survey research methodology was provided by Dick Ellis.

Footnotes:

(1) National Science Foundation. *U.S. Scientists and Engineers. 1986* (NSF87-322) (Washington, D.C.: U.S. Government Printing Office, 1987).

(2) U.S. Department of Labor, Bureau of Labor Statistics, "Employment by Occupation and Industry, 1986 and Projected 2000 Alternatives" (computer printout). See also the reference, below, to the *Monthly Labor Review*.

(3) Committee on the Education and Utilization of the Engineer, *Engineer Education and Practice in the United States. Foundations for Our Techno-Economic Future* (Washington, D.C.: National Academy Press, 1985).

(4) Committee on the Education and Utilization of the Engineer, *Engineer Employment Characteristics* (Washington, D.C.: National Academy Press, 1985).

(5) Committee on the Education and Utilization of the Engineer, *Engineering Infrastructure Diagramming and Modeling* (Washington, D.C.: National Academy Press, 1986).

(6) Committee on Data Needs for Monitoring Labor-Market Conditions for Engineers, *Engineering Personnel Data Needs for the 1990s* (Washington, D.C.: National Academy Press, 1988).

(7) *Ibid.*, page v.

(8) Bureau of Labor Statistics, "Employment and Earnings" (Washington, D.C., U.S. Department of Labor, January, 1987); reprinted in Betty M. Vetter and Eleanor L. Babco, *Professional Women and Minorities: A Manpower Data Resource Service* (Washington, D.C.: Commission on Professionals in Science and Technology, December, 1987, pp. 90-93).

(9) The New York Times, September 7, 1988, cited in "Briefing" column.

(10) Bureau of Labor Statistics, Monthly Labor Review (Washington, D.C., U.S. Department of Labor, September, 1987, pp. 79-81).

(11) *Ibid.*, pp. 49-57.

(12) The New York Times, October 23, 1988, cited under commentary "Becoming a Science."

ENGINEERING MANPOWER BULLETIN

This 101st edition of the Engineering Manpower Bulletin commemorates the Engineering Manpower Commission's 40th year of service to the profession and the nation. It examines broad trends in engineering manpower from 1950 to the present, including increases in the number of engineers, changes in compensation, increased participation by women and minority groups in the profession, and trends in the activities of the Commission itself.

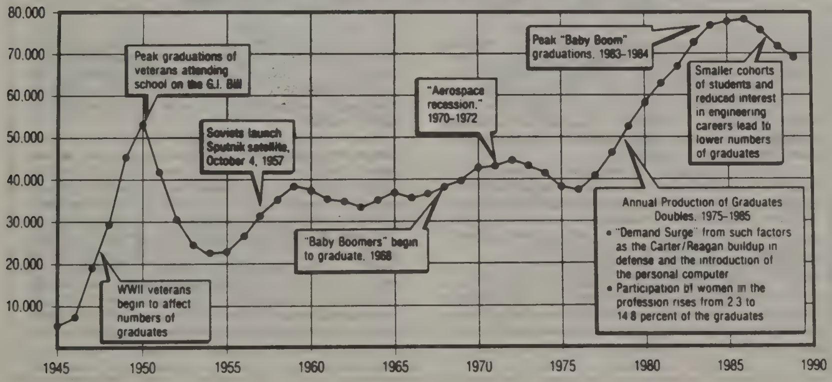
The Engineering Manpower Commission conducts annual surveys of engineering enrollments, degrees, and salaries, and issues reports and bulletins on these subjects and on other topics related to the production and utilization of engineers. Inquiries about EMC's publications and activities are welcome. Contact R. A. Ellis, Director of Manpower Studies, American Association of Engineering Societies, 415 2nd Street N.E., Washington, D.C. (202-546-2237).

ENGINEERING MANPOWER TRENDS, 1950-1990

On September 15, 1950, in recognition of widespread concerns about military manpower needs and the effect of the draft on crucial questions of U.S. economic and industrial readiness, the Engineers Joint Council (EJC)—the predecessor of the American Association of Engineering Societies—approved a recommendation to "... establish an Engineering Manpower Commission charged with the responsibility of (a) developing policies and procedures designed to secure the most effective use of engineering skills and experience in industry and in government (civilian and military) during the emergency and (b) taking necessary steps within the scope of EJC to put such policies and procedures into practice . . ."

The "emergency" to which the EJC's resolution referred was, of course, the Korean War (see the sidebar "The Way It Was" on page 2). Entire reserve units were being recalled to active duty in the armed forces, sweeping up professional and technical workers without regard for any impacts on the civilian side of the war effort or on the economy in general. As requirements for drafting military personnel soared, industry and government authorities realized that special efforts would be needed to ensure that "each man served

FIGURE 1
AWARDS OF FIRST PROFESSIONAL DEGREES IN ENGINEERING, 1945–1989



where the nation needed him most." Specifically, vital industry operations had to be preserved, the education of professional workers had to be maintained, and skilled technical people had to be appropriately utilized in the armed services as well as in industry. EMC's early activities dealt with these matters, as in "Manpower Utilization and National Security," a 35-page booklet issued in 1952.

In later years, questions of military manpower continued to come before the Commission, especially during the 1960's and early 1970's when the Viet Nam conflict renewed interest in issues of military service and occupational deferments. EMC issued two major publications on these subjects, the *Employer's Inventory of Critical Manpower* and *Selective Service and Military Policies on Classification, Deferment, and Delay*. The Commission organized workshops throughout the country to explain how employers of scientists and engineers could obtain assistance in their efforts to hold on to their technical workers, including direct help from EMC and from the similar Scientific Manpower Commission (now the Commission on Professionals in Science and Technology). The two Commissions worked closely with industry, academic institutions, the Department of Defense, and individual draft boards. Brigadier General C. S. Dargusch, who had been deputy to the chief of the Selective Service System, General Lewis B. Hershey, served as legal counsel to EMC and played an important role for many years in the Commission's work on the military draft and technical manpower policies.

Although the Engineering Manpower Commission was originally organized to respond to problems raised by a military emergency, from its inception EMC also dealt with broader, more fundamental questions, such as assessments of the supply of, and demand for, engineers; compensation of technical personnel; and the increasing importance of women and minorities to the profession. Those topics have become the principal focus of the Commission's work today.

The Production of New Engineers

In 1950, well over 50,000 bachelor's degrees in engineering were awarded by colleges and universities in the United States. This level of production was unprecedented. It was a direct result of the decisions of hundreds of thousands of World War II veterans to attend college, taking advantage of their benefits under the G.I. Bill of Rights. After 1950, participation in higher education dropped back to normal levels, and nearly thirty years would pass before the annual number of engineering B.S. degrees reached this point again (see Figure 1).

The Commission's interest in questions of supply and demand quickly led it to issue such publications as "The Critical Shortage of Engineers" (1951) and "How Your Company Can Help Promote Engineering as a Career" (done with the Advertising Council in 1953). Tracking the annual production of new engineers was essential for assessments of trends affecting the engineering work force, and EMC's first analysis of the "Distribution of Engineering Graduates and Demand for Engineers" appeared in 1953. Degree production data were included in the Commission's early studies of the placement of engineering graduates. Until the mid-1960's, the source of these crucial statistics on engineering enrollments and degrees was the U.S. Office of Education. Changes at that agency in the latter half of the decade made it impossible to continue to depend on the government for timely data, and in 1967 EMC agreed to begin collecting enrollment and degrees statistics itself, not just for engineering programs but also for engineering technology.

THE WAY IT WAS: THE U.S. FORTY YEARS AGO

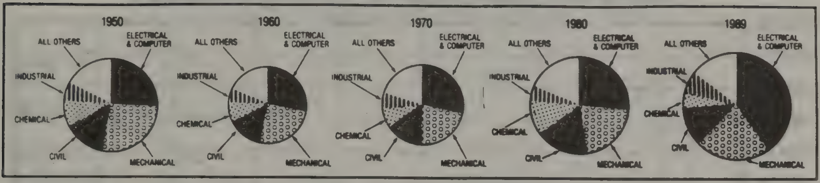
In June, 1950, a savage ground war began in Korea, escalating rapidly into full-scale conflict. Headlines in the *Washington Post* September 1 were typical: "Yank Counterattack Drives Enemy Back After All-Out Assault Pierces U.S. Line." In a related page one story, ". . . Rep. Carl Vinson (D. Ga.), chairman of the House Armed Services Committee . . . confirmed . . . that married men and men with dependents, hitherto exempt from Selective Service calls, would soon be made subject to the draft . . ."

Only five years had passed since the end of World War II. In 1945, the United States had seemed invincible; no one else possessed the atomic bomb. This security did not last long. By 1950, the Soviets had their own nuclear weapons. "Washington is a target," said the *Post*, commenting on needs for civil defense and a proposal to disperse government agencies into the surrounding countryside.

Talk of a third world war was in the air, yet at the same time the country was entering a period of unprecedented prosperity. People were told that they could count on a constant flow of new marvels of technology. In 1950, television sets were moving from taverns into homes, and on September 3, the *Post* introduced its "TV Week" supplement. State police were beginning to experiment with the use of radar to enforce speed limits. An automotive innovation, the tinted windshield, was announced by Buick. DuPont introduced dacron, a polyester fiber. The National Bureau of Standards reported that it had successfully tested SEAC, one of the first general-purpose computers, noting that the machine could calculate a seven-digit prime number in just forty minutes.

In many ways, life in the U.S. in 1950 was still in the process of changing from wartime to postwar conditions. The great suburban boom had begun, and a new detached house could be purchased for $10,000. Women, who had replaced men on the college campuses and in factories and businesses during World War II, were encouraged to become full-time homemakers, leaving the jobs for returning veterans. Most stores and restaurants were local establishments that sensed a growing threat from "chain stores." Movies were shown only in theaters, and automobiles came from Detroit, not from abroad. The national system of interstate superhighways did not exist. Passenger airline service was dependent on propeller-driven aircraft, and major league baseball teams traveled by train. There were a few black athletes in the big leagues, but segregation of the races was still taken for granted in most aspects of American life.

FIGURE 2
TRENDS IN THE DISTRIBUTION OF SPECIALTY CHOICES, 1950–1989
("Pies" are proportionate to the number of B.S. degrees awarded each year)



Throughout the 1950's and 60's, the employment market for the profession remained favorable, but this changed with the the so-called "aerospace recession" of the early 1970's. Commenting on rapid changes in the employment outlook ("The Future Supply of Engineers 1970-1978," *Engineering Manpower Bulletin* No. 17, September, 1970), John Alden's observations are relevant today. Acknowledging that the recession had confounded all predictions of the need for engineers, he said "Observers may wonder how the engineering manpower picture can change so suddenly from one of chronic shortage to an apparent surplus . . . The answer, of course, is that the need for more engineers is basic and long range while the immediate job market is determined by all kinds of other factors." By 1971, the effects of the recession had become grim enough for the Commission to issue a bulletin dealing with unemployment and underemployment, drawing on material in a survey commissioned by the National Science Foundation. The economic climate remained uncertain through the mid-1970's. A growing public understanding of the vulnerability of engineers to the ups and downs of business cycles and the economy may have contributed to weakened student enrollments in engineering colleges during the middle of the decade.

However, the annual production of new bachelor's degrees in engineering recovered by the late 1970's, surpassing the levels reached in 1950. This surge in the generation of new bachelor's degrees in engineering continued through the mid-1980's, fueled by strong demands for new graduates, increased participation in the profession by women, and the fact that starting salaries for engineers were keeping up with inflation (see below for more comments on trends in compensation). By 1985, the annual numbers of new engineering graduates had doubled, compared to the levels observed just ten years earlier.

Since 1986, the production of new B.S. degrees in engineering in the U.S. has been declining, primarily due to demographic changes in the annual numbers of high school graduates and to reduced student interest in engineering careers, compared to 1982 when the profession's appeal reached unusually high levels. At this writing, interest in the profession is no longer falling, but demographic influences alone will probably cause further decreases in the annual production of new engineers throughout most of the 1990's. Similar trends will also affect engineering education in developed countries outside the United States.

During the past forty years, significant shifts have occurred in the propensity of graduates to choose different major engineering disciplines. These trends are depicted in Figure 2, which charts the distribution of graduates' specialties. In 1950, mechanical engineering was still the most popular degree, but now the fields of electrical and computer engineering account for almost 40 percent of the bachelor's awards.

There have been other kinds of changes in the makeup of engineering disciplines. Statistics for 1950 do not recognize the fields of biomedical, computer, environmental, nuclear, or systems engineering, all specialties that have developed during the last 40 years.

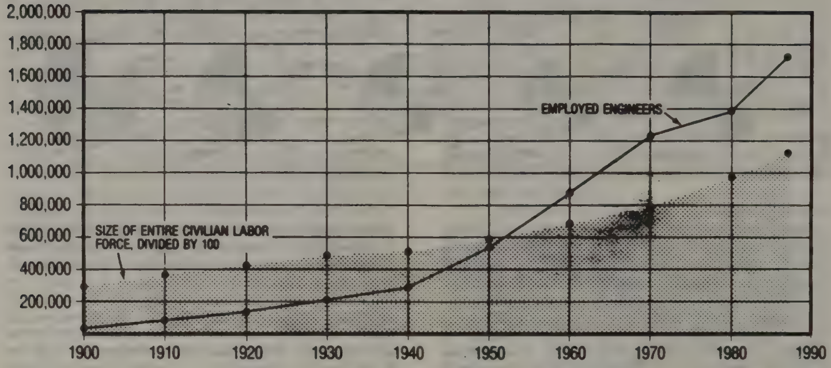
The Work Force

Another statistical threshold was being crossed by the engineering profession in the early 1950's. Figure 3 plots the number of employed engineers, as counted by U.S. Censuses and Current Population Surveys, from the turn of the century to the present. The plot for the time series on the engineering work force is superimposed on a graph depicting the growth of the entire U.S. civilian labor force. To facilitate comparisons, the numbers for workers in the civilian labor force have been divided by 100. For example, for 1950 the figure depicts a total civilian labor force of 59.2 million workers, of whom 535 thousand were engineers.

Since the end of World War I, engineering employment has grown more rapidly than has the labor force as a whole. By the 1930's, the profession accounted for about one-half of one percent of the employed workers; by the early 1950's, engineers had doubled their relative share of all jobs. The engineers' share of U.S. employment has continued to increase, and today engineering is one of the largest professional occupations in the nation. There are more engineers by far than there are lawyers, doctors, or scientists of all types. Engineers outnumber accountants, the largest single management occupation. There are even more engineers than elementary school teachers, although when secondary educators are counted, teaching remains the largest profession of all.

Dennis Swyt of the U.S. National Institute of Standards and Technology has examined these kinds of long-term time series data for occupations. His studies suggest that the growth of engineering is a part of a larger long-term trend away from 19th century economies, in which labor forces were composed mostly of agricultural, blue collar, and service workers, toward 21st century economies in which the administrative and technical occupations will be the major components of employment. The emerging

FIGURE 3
NUMBER OF EMPLOYED ENGINEERS IN THE U.S., 1900-1987
(SUPERIMPOSED ON A TREND LINE FOR THE ENTIRE CIVILIAN LABOR FORCE, WITH NUMBER OF TOTAL WORKERS DIVIDED BY 100 TO FACILITATE COMPARISONS)



Source: Self-reported occupational statistics from the U.S. Census and Current Population Surveys

importance of global, as opposed to national, employment markets complicates such analyses. We will look at these kinds of questions at greater length later this year, in a forthcoming issue of this bulletin that will deal with possible developments from 1990 through 2030.

Compensation Trends

"Engineers Earning More But Enjoying It Less." This was the issue title for *Engineering Manpower Bulletin* No. 33, issued January, 1977, the first of these bulletins to be exclusively devoted to summarizing an EMC compensation survey. The theme of the piece was that inflation had eroded increases in the absolute compensation of engineers, to the extent that the average practitioner was worse off than in the past. This conclusion could apply to engineering pay today (see Figure 4).

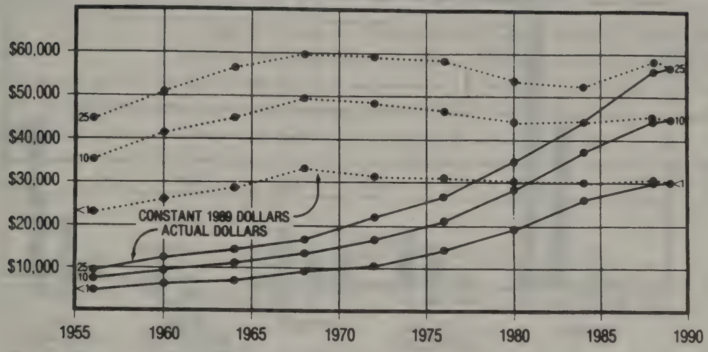
Compensation surveys were among the earliest undertakings of the Commission. A pilot effort was done in 1953. A greatly enlarged version of that study was carried out in 1956, and consistent time series data on engineering salaries have been available from EMC ever since.

The data for actual dollar salaries, plotted at four-year periods from 1956 to 1988 with additional information for 1989 added at the end of the series, show how compensation for engineers has changed. In 1956, the median base pay for engineers in their first year of work was $5,000 per annum; in 1989, it was over $30,000. For those with ten years of experience in the profession, the medians were $7,800 in 1956 and $45,250 in 1989. For those with 25 years of experience, the medians were $9,800 and $57,250.

These improvements in absolute pay can be deceptive. For the profession as a whole—there are important exceptions, discussed below—improvements in general engineering compensation since 1970 have often failed to keep up with the effects of inflation. These movements are depicted in Figure 4 with dotted lines, in terms of constant 1989 dollars. The data show that in the late 1960's, constant-dollar engineering compensation reached its highest levels to date. In the late 1970's, the salaries of experienced engineers did not rise rapidly enough to keep pace with double-digit inflation of the dollar. Starting rates for new graduates were a notable exception to this trend, as noted earlier, and this led to a compression in the range of pay between inexperienced and experienced people. There was some recovery in rates of pay during the middle of the decade, but recently the general trends for constant-dollar engineering compensation have tended to be flat or negative. The use of bonuses and other forms of special incentive compensation for engineers has been rising, so EMC's data are increasingly likely to understate total pay, especially for the most proficient and more senior workers.

A weakness of broad summaries such as those in Figure 4 is that they represent only central tendencies for engineering as a whole, and do not necessarily apply to any particular component of the profession. For example, the trend of constant dollar compensation for engineers in the petrochemical sectors has been better than average, continuing to improve well into the 1980's. On the other hand, the trend for engineers in the electronics industry has been somewhat worse than average; in particular, this group does not seem to have experienced the recoveries in constant dollar pay that some others enjoyed in recent years. Many other exceptions to the general trends can be uncovered when analysis shifts to the level of particular enterprises or to that of individual engineers.

FIGURE 4
TRENDS IN MEDIAN ENGINEERING COMPENSATION, 1956–1989:
ACTUAL DOLLARS VS. CONSTANT 1989 DOLLARS, FOR
ENGINEERS WITH LESS THAN ONE, TEN, AND 25 YEARS' EXPERIENCE



Source: Engineering Manpower Commission salary surveys, 1956–1989

The Expansion of Opportunity

Engineering degrees have been awarded to women since the 19th century, and Howard University has been offering programs in engineering since 1911, but in 1950 it was still realistic to assume that the profession was almost entirely limited to white men. Then came the civil rights revolution of the 1960's and the rise of African-American, Hispanic, and other kinds of ethnic consciousness, and of the feminist movement. Issues of the *Engineering Manpower Bulletin* titled "Women in Engineering" began to appear in May, 1972 and have been published regularly since that time. African American students began to be counted separately in the Commission's annual degree and enrollment surveys in 1970, and tracking of Hispanic Americans, Native Americans, and Asian Americans was instituted in 1973. That year, the Commission also issued a special publication called "Minorities in Engineering," a title also continued in subsequent years in the *Bulletins*.

Figure 5 shows how these groups are accounting for a steadily increasing share of engineering degrees. Only 0.2 percent of the B.S. awards in 1950 went to women; by 1989, the female share of these degrees was 15.3 percent. In some engineering disciplines, the women's share of degrees has been notably higher, particularly in chemical and industrial engineering where for some time they have accounted for roughly one-quarter of the graduates. Gains for African Americans, Hispanic Americans, and Native Americans have been less dramatic. The share of all bachelor's degrees in engineering awarded to members of these three under-represented ethnic groups has doubled since the early 1970's. The Commission also tracks Asian Americans, but they are not at all under-represented in engineering.

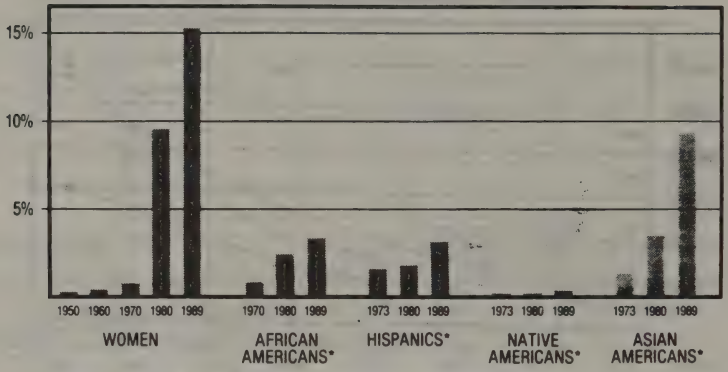
The engineering community has become well aware that the work force will be increasingly composed of women and ethnic minorities, and that full participation in engineering by these groups of people is an essential condition for the continued effectiveness of the profession. To build on the progress achieved to date, new initiatives—some of them large-scale and national in their scope—are now underway to encourage women and minorities to become engineers. These efforts will continue for many years to come. The concerns of the profession encompass an understanding that the education of all our children is going to have to be substantially improved if Americans are to compete in the 21st century.

The Engineering Manpower Commission Today

Now in its fortieth year of service, EMC's work on manpower trends has included guidance for policymakers in government, industry, and the profession; occasional conferences and other forums; and the production of several hundred statistical reports, bulletins, and special studies. Figure 6 provides time line data for several of the Commission's longest-running projects. Only major products, such as studies of the salaries of engineers in industry, are flagged in this chart. For example, the line for the compensation studies does not take note of the related reports on the salaries of technicians and technologists that EMC issued from time to time in the past, nor does it take account of the studies of faculty pay that the Commission has been doing since the 1950's.

The Commission is entirely composed of volunteers. Several hundred engineers have served as commissioners since EMC was founded in 1950, most for two-year terms, some for a decade or

FIGURE 5
SHIFTS IN PARTICIPATION IN ENGINEERING BY WOMEN AND MINORITIES:
PERCENTAGES OF BACHELOR'S DEGREES, SELECTED YEARS, 1950–1989



*Excluding graduates of the University of Puerto Rico and foreign nationals.
Source: Engineering Manpower Commission degree surveys and U.S. Office of Education data

more. The most senior member, very active today, has more than 33 years of service. These commissioners, listed in Figure 7, provide broad representation from industry, government, education, and professional societies. They include experts on corporate human resource management and engineering compensation, deans of engineering schools, and researchers at some of the nation's major engineering laboratories. Four are women. There are African American, Hispanic, Native American and Asian American members. A newly established program for institutional supporters is underway, and will add a growing number of additional affiliations.

EMC has long-standing ties with the Commission on Professionals in Science and Technology, and works closely with the Office of Science and Engineering Personnel at the National Research Council (the action arm of the National Academies of Science and Engineering), and with federal agencies like the National Science Foundation and the U.S. Bureau of Labor Statistics.

As a part of the American Association of Engineering Societies, EMC reports to the Board of Governors of that organization; on policy matters, it coordinates with the AAES Engineering Affairs Council. The production of surveys, reports and bulletins is supervised by commissioners, who determine matters of content, general technical approaches, and scheduling, and who provide editorial review. Day-to-day activities of survey design, programming, data collection and analysis, and report writing are handled by the AAES Manpower Studies Department, a small (three person) survey research shop. This collaboration between commissioners who are experts in the substance of the engineering profession and technical specialists with extensive experience in the production of research work helps EMC to meet its goals of providing products that are both authoritative and timely.

The Commission is issuing its products, which now include machine-readable versions of its educational surveys, more rapidly than ever. Its most recent survey of engineering compensation covered more than 120,000 people in industry and government, providing data on salaries as of February, 1989 that were released in printed reports by July. EMC's survey of engineering degrees awarded in 1989 provided comprehensive coverage of each of the more than 315 U.S. institutions with engineering programs, plus data from nearly 300 schools of engineering technology, and was released in December. The Commission's study of 1989 Fall engineering and technology enrollments covered more than 620,000 students and was released in early April of 1990. No other source of such data is this swift. No other source provides such detailed information on the numbers of women, minorities, or foreign nationals in specific specialties at particular schools.

As EMC looks ahead to the 21st century, it is apparent that national interest in engineering manpower is greater than ever before. To deal with such issues as U.S. competitiveness in a global economy, the changing composition of the work force, and the impact of emerging technologies requires accurate, timely data on the training and utilization of engineers. The Commission expects to serve during the next 40 years as it has in the past, as a key source of information that will be needed by government, industry, and the profession.

—R.A. Ellis

FIGURE 6
MAJOR CONTINUING PROJECTS OF THE ENGINEERING MANPOWER COMMISSION, 1950–1990

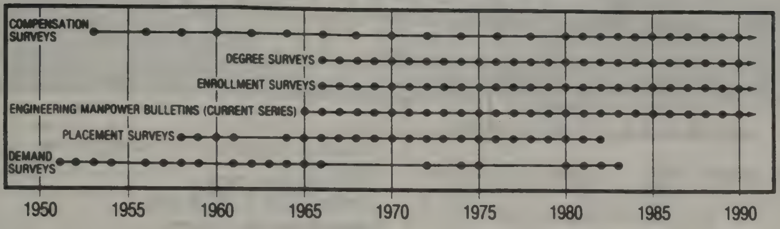


FIGURE 7
MEMBERS OF THE ENGINEERING MANPOWER COMMISSION, MAY, 1990

Commissioner	Institutional Affiliation	Engineering Society Representation*
Mr. Don C. Brown, Chairman	Sun Company/Oryx (retired)	American Institute of Mining Engineers
Mr. Paul B. Wood, Past Chairman	Port Authority of N.Y. & N.J.	At Large
Mr. Luke H. Noggle, Vice Chairman	Westinghouse Electric Corporation (retired)	At Large
Dr. William M. Sangster, Vice Chairman	Dean, College of Engineering, Georgia Tech	At Large
Mr. Peter S. Adams	E. I. duPont de Nemours & Co.	At Large
Dr. Eleanor Baum	Dean, School of Engineering, Cooper Union	At Large
Dr. Fred Beaufait	Dean, College of Engineering, Wayne State University	Engineering Society of Detroit
Dr. Theodore A. Bickart	Dean of Engineering, Michigan State University	At Large
Dr. William R. Boyle	Oak Ridge Associated Universities	American Nuclear Society
Mr. Charles Day	American Society of Civil Engineers	American Society of Civil Engineers
Mr. Edward J. Doyle	New Jersey Bell Telephone Co. (retired)	Institute of Electrical & Electronic Engineers
Ms. Patricia L. Eng	Nuclear Regulatory Commission	Society of Women Engineers
Mr. Earl E. Gottsman	Capitol Institute of Technology	At Large
Mr. Dwight Gorneau	IBM	American Indian Science & Engineering Society
Mr. Lewis G. Grimm	Frederic R. Harris, Inc.	American Society of Civil Engineers
Mr. John Hannabach	Georgia Tech	At Large
Mr. David A. Kearney	Westinghouse Electric Corporation	At Large
Dr. Edward T. Kirkpatrick	President, Wentworth Institute of Technology	American Society for Engineering Education
Dr. Charles S. Lessard	Texas A&M University	Institute of Electrical & Electronic Engineers
Miss Barbara A. Montague	E. I. duPont de Nemours & Co.	At Large
Mr. Robert L. Ohrtman	Grumman Corporation	At Large
Dr. David R. Reyes-Guerra	Accreditation Board for Engineering & Technology	At Large
Mr. Michael B. Rubin	David Taylor Research Center, U.S. Navy	American Society of Mechanical Engineers
Mr. Robert Rusek	American Telephone & Telegraph Co.	At Large
Mr. Donald G. Schroeter	Amoco Corporation (retired)	At Large
Mr. Glen J. Snyder	Babcock & Wilcox Co. (retired)	American Society of Mechanical Engineers
Mr. James Donald Strong	U.S. Army (retired)	American Society for Engineering Education
Mr. Neal C. Thompson	Exxon Research & Engineering	At Large
Mr. Steven B. Tucker	General Electric Corporation	At Large
Dr. Glen Vanden Berg	U.S. Department of Agriculture	At Large
Dr. M. Lucius Walker, Jr.	Dean of Engineering, Howard University	At Large
Ms. Mary Ann Zimmerman	TransCentury Corporation	Society of Women Engineers

* All commissioners belong to one or more professional societies. Those commissioners linked with engineering societies in this listing are the formally appointed representatives or alternate representatives to EMC from those organizations.

Institutional Associates

(as of May, 1990. EMC has just begun recruiting these members and will continue to add to their numbers throughout the year.)

Patron Sustaining Associates:

- General Electric Foundation
- National Action Council for Minorities in Engineering

Senior Sustaining Associates:

- Amoco Foundation

Contributing Associates:

- Grumman Corporation
- Society for Mining, Metallurgy, and Exploration, Inc.

Sustaining Associates:

- American Institute of Chemical Engineers
- E. I. duPont de Nemours
- Eastman Kodak Company
- Exxon
- Procter & Gamble Company
- Westinghouse Electric Corporation

WE ARE MOVING

After June 26, 1990, AAES' address and phone numbers will be:

American Association of Engineering Societies, Inc.
Suite 608
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Washington, D.C. 20036-3690

Office phone: (202) 296-2237
FAX number: (202) 296-1151

ENGINEERING MANPOWER BULLETIN

ENGINEERING
MANPOWER
BULLETIN

This 104th Engineering Manpower Bulletin considers both conventional projections and less common indicators of the demand for engineers. It does not attempt to derive new predictions of demand. Rather, the bulletin aims to set the stage for improved thinking about this topic. It calls for timely and more frequent surveys to understand the nature of demand, as well as its level.

Inquiries about the Engineering Manpower Commission's activities and reports are welcome. Contact R. A. Ellis, Director of Manpower Studies, American Association of Engineering Societies, (202) 296-2237.

DEMAND FOR ENGINEERS: A REVIEW OF CURRENT THINKING

Among the responsibilities of the Engineering Manpower Commission is the study of the demand for engineering and technical manpower. The Commission has been faced with the dilemma of balancing the need for responsible long-term policy guidance against the uncertainties affecting all projections.

Since 1951, one year after it was founded, the Commission has carried out 21 demand studies. The last series of four surveys, during 1980-1983, studied patterns of short-term demand. EMC also attempted to compare and validate surveys of individual members of engineering societies against surveys of engineering employers. Both types of surveys forecast similar trends, but the accuracy of the forecasts left much to be desired.

This *Engineering Manpower Bulletin* provides background which should be considered when designing future demand surveys. It discusses a number of concepts and assumptions relevant to projections. These are:

- models based on economic scenarios;
- engineering needs of competitive modern societies;
- potentials of new technologies for engineering growth;
- immigration patterns as an indicator of demand;
- needs for new structures in the engineering profession; and
- short-term effects of Defense budget reductions.

This is a review of current thinking, not a report of new research, and we have not reached firm conclusions in this *Bulletin* about the demand for engineers in the near term or more distant future. However, we believe that the discussion does provide an improved framework for the treatment of this topic; it clarifies the effect of some of the factors that influence demand; and it leads to suggestions for further work.

MODELS BASED ON ECONOMIC SCENARIOS

The most familiar projection of engineering demand in the civilian labor force is from the U.S. Bureau of Labor Statistics (BLS) and is shown in Table 1 (Silvestri, 1989). Labor force projections are provided by a BLS demographer. Macroeco-

TABLE 1
HISTORICAL AND PROJECTED EMPLOYMENT OF ENGINEERS*
(numbers in thousands)

Engineering Specialties	Total Employment			Percentage Change per Year, 1988-2000		
	1986	1988	2000	Low	Moderate	High
Aero and Astro	53	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Chemical	52	[illegible]	[illegible]	[illegible]	1.3	[illegible]
Civil including Traffic	199	[illegible]	[illegible]	[illegible]	1.4	[illegible]
Electrical and Electronic	401	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Industrial (exc. Safety)	117	[illegible]	[illegible]	[illegible]	1.3	[illegible]
Mechanical	233	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
All Engineers	1,571	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

* Data on actual employment for 1986 from Silvestri et al., "A Look at Occupational Employment Trends to the Year 2000," *Monthly Labor Review* (Washington, D.C., Bureau of Labor Statistics, Vol. 110, No. 9, September 1987), p. 51. Data on actual employment for 1988 and projected employment for 2000 from Silvestri et al., "Projections of Occupational Employment 1988-2000," *Monthly Labor Review* (Washington, D.C., Bureau of Labor Statistics, Vol 112, No. 11, November 1989), p. 51. Employment figures for the year 2000 are the BLS "moderate" projections; average annual percentage increases compare low, moderate and high projections.

nomic forecasts are derived from a Data Resources Inc. (DRI) macroeconomic annual model of the U.S. economy, using low, moderate, and high growth rate estimates for 200 exogenous variables. It should be noted that all projections cited below have differing specific definitions of the engineering population (Alden, 1989).

The BLS forecast of an overall growth of civilian engineering employment of 15 to 37 percent between 1988 and the year 2000 (which translates to 1.2 to 2.7 percent per year, depending on whether low, moderate, or high assumptions are used) compares with forecasted growth of 8 to 22 percent (0.6 to 1.67 percent per year) for overall civilian employment in all occupations. Macroeconomic assumptions that influence this model include a drop in real Department of Defense purchases of 1.3 percent per year for the moderate projection, a drop of 1.5 percent per year for the low projection, and a rise of 0.5 percent per year for the high projection. In all these cases, most of the expected growth is for electrical and electronic engineers.

Under the "moderate" set of growth assumptions, BLS forecasts 1,760 thousand employed engineers in the year 2000, compared with a previous moderate forecast of 1,815 thousand engineers made by the same agency two years earlier (Silvestri et al., 1987).

Similarly, the National Science Board (NSB), using a similar DRI model, projects a growth of 2.2 percent per year for engineers in private industry for the 1988-2000 period (NSB, 1989), based on employment of 1.275 million engineers in 1988.

A slightly earlier study by Collins of the National Science Foundation (NSF) for the 1986-2000 period projected gr· ·hs of 1.9 to 2.7 percent per year for engineers and 0.9 to 1.· for total civilian employment. Using those growth rates, pl· estimates of retirement rates (assuming age 65 retirem· ·) and the assumption that every year, three to four percent of all engineers will migrate out of the profession, Collins found that the cumulative total vacancies to be filled in engineering during the years 1987 through 2000 would range from 1.53 to 1.78 million engineers. Based on credible supply scenarios, she concluded that a cumulative shortage of two to 13 percent of 1987-2000 demand for natural scientists and engineers could be projected (Collins, 1988).

On the other hand, unemployment rates for engineers rise when Defense cutbacks occur. This has been an explanation for diminished engineering enrollments in the early 1970's (Vetter, 1985. Also see Freeman, 1971, for relationships between demand and enrollment). The 1986 unemployment

TABLE 2
NONACADEMIC ENGINEERS PER 10,000 LABOR FORCE

Country	Date of Survey	Number	Source*
[redacted]			

* NSF data from *International Science and Technology Update 1988* (Washington, D.C. National Science Foundation, NSF 89-307, 1988). Other sources: Bureau of the Census, Center for International Research, "Recent Data on Scientists and Engineers in Industrialized Countries" (Washington, D.C. U.S. Department of Commerce, 1988), and O. Way and E. Jamison, U.S. Bureau of the Census, Center for International Research, "Scientists and Engineers in Industrialized Countries" (Washington, D.C. U.S. Department of Commerce, 1986).

rates of 2.4 percent for new engineering bachelor's graduates and 1.2 percent for new master's graduates (NSB, 1989), and the first quarter 1990 unemployment rates of 2 percent for all engineers (Rivers, 1990b) compare with peak unemployment rates of about 3 percent reported for new 1976 graduates and for all engineers in 1971.

In the face of such uncertainties, more frequent short-range studies are needed to track engineering demand and the enrollment consequences of demand. It may be possible to tie the data collection needed for this work to improvements in the BLS Establishment Survey suggested by Rivers (1990a).

ENGINEERING NEEDS OF COMPETITIVE MODERN SOCIETIES

An alternative to macroeconomic modelling of demand is the consideration of the "engineering intensity" of modern industrial societies. This approach can yield a "ball park" estimate of the number of engineers required to maintain such a society.

As shown in Table 2 (NSF, 1989a), non-academic engineers per 10,000 labor force members in modern industrialized societies range from 104 to 189 with a mean of 159 and standard deviation of 37.1. The definition of "engineer" in these international statistics, as in American statistics (Alden, 1989), is hard to pin down, but it may be noted that in 1986, the BLS reported 1.371 million employed engineers in a civilian labor force of 117.837 million, a ratio of 161 per 10,000, so that the ratio in the range of 159 is not unreasonable (Silvestri et al., 1987).

Using the projected range of the Civilian Labor Force shown in Table 3 (Fullerton, 1989), the demand for engineers in the year 2000 would be 2,189 to 2,334 thousand workers, well above the BLS projection shown in Table 1.

It may be noted that even though the proportion of engineers in the U.S. labor force is similar to that in Japan,

TABLE 3
PROJECTED TOTAL CIVILIAN LABOR FORCE
IN THE YEAR 2000*
(level in thousands)

High Projection	Moderate Projection	Low Projection
[redacted]	[redacted]	137,684

* Fullerton, H.N. Jr., "New Labor Force Projections, Spanning 1988 to 2000," *Monthly Labor Review* (Washington, D.C.: Bureau of Labor Statistics, Vol. 112, No. 11, November 1989, p. 9).

TABLE 4
EMERGING TECHNOLOGIES:
ESTIMATED SALES BY YEAR 2000 IN BILLIONS OF DOLLARS*

Continuing Growth Trend:	Possible Structural Change:
[redacted]	[redacted]

* List and estimates from Technology Administration, U.S. Department of Commerce, *Emerging Technologies: A Survey of Technical and Economic Opportunities* (Washington, D.C., U.S. Dept of Commerce, Spring, 1990, p. viii). Distinctions between continuing growth trends and possible structural changes were made on the basis of the author's judgment.

Japanese industry funded 69 percent of their R&D in 1985, while in the U.S., industry funded 49 percent (NSF, 1989a). U.S. funding was related to strong government support of defense-related R&D. Hence, surveys of the comparative utilization of engineers in industrialized countries may be called for. On the U.S. side, an investigation of utilization in this country undertaken a few years ago concluded that "American engineers are highly under-utilized" (Weinschel and Jones, 1986).

POTENTIALS FOR NEW TECHNOLOGIES FOR ENGINEERING GROWTH

The growth and variety of engineering demand in the 1970's and 1980's has been greatly affected by the growth of electronic and computer technologies.

By their nature, econometric models project demand on the basis of historical trends, so the changes of growth in advanced technologies are not easily weighted.

One view of "emerging technologies" is represented by the U.S. Department of Commerce (DOC) survey (Technology Administration, U.S. Department of Commerce, Spring, 1990). The twelve emerging technologies defined by the Department are shown in Table 4. The majority of these represent a continuing growth of electronics and computer technology. Some of them, which we have arbitrarily shown in a separate column in the table, represent other technologies that may be in earlier stages of an expanding growth pattern which could lead to different trends in structures of engineering demand. As in the case of electronics and computer technology, some of these fields may require redefinition of the fields covered by engineering manpower statistics.

Science magazine (Guyer et al., 22 Dec 1989) has published a list of the 18 "big" science stories of 1989 (see Table 5). Again, we have arbitrarily broken out a column representing technologies which might lead to different structures of engineering demand.

Another view of "advanced technologies" is provided by reviewing activities of the more than 100 Japanese national research institutes, 55 of them in Tsukuba Science City. A few categories of high priority are membranes for separating organic liquids, advanced materials for "ultrasevere" environments, and control of pollution (Myers et al., Feb 1990).

Among other technologies which might have potential for changing the structure of engineering demand are nanotechnology (Anonymous, Dec. 9, 1989), supercomputers (Basta, Dec. 1989), engineering megaprojects in developing countries (Fromson, 1988), and design and production of prostheses and artificial organs.

There does not appear to be a dearth of technological opportunities which might alter the structure of engineering demand. At issue is the ease with which technological opportunities will be exploited.

IMMIGRATION PATTERNS AS AN INDICATOR OF DEMAND

As shown in Table 6 (NSF, 1989b), immigration has provided about 7,000 engineers a year to the U.S. economy, although the number dropped to 3,900 in 1974, possibly because of the U.S. engineering unemployment peak in 1971. In 1987, 1,544 of the 8,340 immigrant engineers came from India. In 1986, the largest source nation, Taiwan, provided 888 of the 8,389 immigrant engineers. There is clearly a relationship between international conditions and U.S. labor market conditions that interact to determine employment of immigrants.

The more significant indicator of the effect of immigration is entrance to the labor force. In 1981-1985 foreign nationals receiving U.S. Ph.D's provided 30-40 percent of Ph.D entrants to the U.S. engineering labor force (Finn, 1988).

At the present time, some distortion of these patterns may occur because of Russian immigration (Holden, June, 1990).

Current projections of engineering demand appear adequate to support current levels of immigration.

NEEDS FOR NEW STRUCTURES IN THE ENGINEERING PROFESSION

Some of the forces driving the restructuring of the engineering profession include:

- efficient computerization of traditional design functions;
- integration of design and manufacturing;
- growing internationalization of large enterprises; and
- increasing needs for technical expertise in the service industries such as banking and finance.

The trends of computerization and integration are drives to reduce costs and to shorten the production cycle (Anderson, 1990). They may result in a need for fewer but more highly trained engineers.

TABLE 5
18 BIG SCIENCE STORIES OF 1989

Potential for Affecting Structure of Engineering Demand in the 1990's	Other "Big" Science Stories
Polymerase Chain Reaction	**Synthesis of Palytoxin**
Antibody Production by Genetically Engineered Bacteria	**Development of Abortion Drug RU486**
Advanced Materials via Advanced Processes	**Voyager and Phobos Missions**
Scanning Tunneling Microscope to Generate Lines & Holes	**Immunosuppressive Drug FK506**
Effects of Greenhouse Gases and Ozone Depletion	**Cystic Fibrosis Gene Identification**
Synthetic Blood Products, e.g. Epogen Kidney Hormone	**New AIDS Drug ddI**
Cold Nuclear Fusion Possibility	**Generation of Z-Zero Bosons**
Earthquake Engineering	**RNA Molecule Self-Sufficency**
Neural Networks	**Balance of Oncogenes and Tumor-Suppressor Genes**

* Based on R. L. Guyer and D. E. Koshland, "The Molecule of the Year," *Science* (Washington: American Association for the Advancement of Science, Vol. 246, December 22, 1989, pp. 1543-1546). Distinctions between developments with the potential to affect engineering and other "big" science stories based on the author's judgment.

International work has long been common in engineering, primarily in large construction and mining projects. Today the large multinationals are dealing with new technical and economic balances between needs for integration and the needs for local responsiveness (Prahalad, etc., 1987), so that the American engineer needs to be educated for greater global adaptability (Doyle, 1989).

Recent projections of engineering demand have indicated increasing employment in the service industries. In the 1980-1988 period (NSB, 1989), overall engineering employment increased by 3.9 percent per year in all private industry. This increase dropped to 2.4 percent per year in goods-producing industries, but it was 4.8 percent per year in service-producing industries, especially in financial services (13.9 percent per year) and business and related services (6.4 percent per year), which include R&D laboratories. BLS data and projections also confirm these patterns.

Growth in engineering services is related to the increasing importance of services in the overall economy, but in addition the growth reflects a recognition by service industries of the importance of the technical and business skills offered by engineering training.

The Japanese have studied the effect of this trend on their engineering profession "being alienated from manufacturing sector and oriented toward service sector" (Nishigata, 1989). From the view of the future of Japan, they have identified positive and negative aspects as shown in Table 7.

Still another view of engineering was expressed in a newspaper review of an explanation of the logistics of White House operations by John Sununu, a mechanical engineer and the White House Chief of Staff, to Mikhail S. Shkabardnya, an engineer and aide to Soviet Union President Gorbachev (Rosenthal, 1990). "There was no ideology, no policy, no philosophy. It was all process, process, process."

These structural changes make engineering demand harder to survey and pose questions for educational policy.

TABLE 6
IMMIGRANT ENGINEERS, 1967-1988*
(in thousands)

Year	Engineers
1988	[illegible]
1987	[illegible]
1986	[illegible]
1985	[illegible]
1984	[illegible]
1983	6.8
1982	7.9
1979-1981	Not Available
1978	6.8
1977	5.3
1976	9.1
1975	[illegible]
1974	[illegible]
1973	[illegible]
1972	[illegible]
1971	[illegible]
[illegible]	[illegible]
1969	[illegible]
1968	[illegible]
[illegible]	[illegible]
Mean of Available Data	**7.89**
Standard Deviation	**1.34**

* Based on "Immigrant Scientists and Engineers, 1988" (Washington, D.C.: National Science Foundation, Surveys of Science Resources Series, NSF 90-313, 1989, p. 5) and "Immigrant Scientists and Engineers: 1987" (Washington, D.C.: National Science Foundation, Surveys of Science Resources Series, NSF 88-329, 1988).

SHORT-TERM EFFECTS OF DEFENSE-BUDGET REDUCTIONS

At the time this *Bulletin* is being written (late August, 1990), the U.S. Budget for 1991 is being discussed by a joint White House and Congressional Committee. The latest Defense Department statement of the implications of budget modifications on engineering employment, based on the President's Budget submitted April 1989 and the Deparment of Defense's DEIMS computer model, is shown in Table 8 (Stix, November 1989). This forecast is consistent with a reduction of defense spending from six to four percent of GNP. This projection now seems out of touch with current conditions.

NSF has been attempting to evaluate these changing targets. Preliminary estimates based on Department of Defense cuts of about three percent per year are shown in Table 9 (Wilkinson, 1990). IEEE has been working with NSF to evaluate a range of rates of cutting. It should be noted that the 1988 estimate of 1,528 thousand engineers, shown in Table 9, is an NSF estimate based on the same establishment survey data as the 1988 estimate of 1,411 thousand shown in Table 1, but with different assumptions about 1988 occupational distributions. The buildup of ground defense forces resulting from the Iraqi affair should not invalidate the effect of

TABLE 7
POSITIVE AND NEGATIVE ASPECTS OF THE SHIFT OF ENGINEERS TO THE FINANCE AND INSURANCE SECTOR
(JAPANESE VIEWPOINT)*

Positive	Negative
Helps sectors cope with deregulation, diversification, and development across national borders	**Attracts people to jobs in neat offices instead of to making things practically**
Attracts more young people to science and technology, providing larger pool of talent	**Possible danger to base of Japan's industrial activities in terms of human resources**
Better understanding of technology in these sectors	

* Source: C. Nishigata, A. Nakanishi, and Y. Hirano, "Employment Trends of Science and Engineering Graduates" (Tokyo: NISTEP Report No. 1, National Institute of Science and Technology Policy, Science and Technology Agency, June 1989).

TABLE 8
DOD ESTIMATES FOR MILITARY AND CIVILIAN NEEDS FOR ENGINEERS*
(thousands of engineers)

Year	Defense	Non-Defense	Total
1986	256	1,176	1,432
1987	257	1,212	1,469
1988	253	1,259	1,512
1989	252	1,299	1,551
1990	255	1,337	1,592
1991	259	1,375	1,634
1992	264	1,403	1,667
Average Annual Growth per Year, 1986-1992	**0.48%**	**2.98%**	**2.56%**

* Basis: April 1989 budget submission, as reported in G. Stix, "From Swords to Ploughshares," *IEEE Spectrum* (New York, N.Y.: Institute of Electrical and Electronic Engineers, November 1989, p. 46).

anticipated general defense reductions on engineering manpower.

SOME CONCLUSIONS AND SUGGESTIONS

Overall, the demand for engineers in the long run depends on the engineering intensity of the American economy. The potential engineering needs for a competitive modern industrial society are equal to or above the needs projected by econometric models. These needs, however, will not materialize if technical opportunities, which do not appear lacking, are not exploited. It is also clear that the structure and efficient performance of engineering work is changing and that surveying and identifying engineers is becoming harder.

In the short run, we should expect a slackening of engineering demand in defense work, and there is major uncertainty on where and how this slack will be taken up. A drop in advertising for aerospace engineers has been reported (Ellis, 1990). The engineering profession requires frequent establishment surveys to monitor both the realignment of demand and changes in the structure of the profession. In addition to the issues of quantity and direction of engineering demand, a significant issue appears to be "What is the nature of the engineer who will be in demand?"

—Arthur F. Dershowitz

Arthur F. Dershowitz is an emeritus member of the Engineering Manpower Commission and was the supervising Commissioner for its last four studies of demand.

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TABLE 9
PROJECTED ENGINEERING DEMAND, 1988-2000,
ASSUMING DEFENSE CUTS AT 3 PERCENT PER YEAR*
(engineers in thousands)

Year	Engineers	Absolute Increase	Annual Percentage Change in Defense Spending
1988	1,528	N.A.	0.1
1989	1,579	51	-1.8
1990	1,603	24	-2.1
1991	1,624	21	-5.1
1992	1,657	33	-3.9
1993	1,697	40	-3.6
1994	1,725	28	-2.9
1995	1,760	35	-3.0
1996	1,783	21	-1.9
1997	1,816	31	0.0
1998	1,840	24	0.0
1999	1,879	35	0.0
2000	1,915	36	0.0

* Basis: R. K. Wilkinson, personal communication of work in progress for the National Science Foundation, 1990. Estimate of 1,528 thousand engineers for 1988 is based on the same establishment surveys as the 1,411 thousand estimate reported by BLS in Table 1, but uses NSF updates of estimation values in the BLS occupational employment matrix.

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The Engineering Manpower Commission's 40th Anniversary Conference:

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The Engineering Manpower Commission, now entering its 40th year of service to the profession and the nation, is composed of 32 volunteers who represent industry, government, academia, and the professional engineering societies. A new associate program for industry and other institutional affiliates was begun this year. As of June 1, these associate members included:

Patron Sustaining Associates:
- General Electric Foundation
- National Action Council for Minorities in Engineering

Senior Sustaining Associates:
- Amoco Foundation

Sustaining Associates:
- American Institute of Chemical Engineers
- Eastman Kodak Company
- E. I. duPont de Nemours & Company
- Exxon
- Procter & Gamble Co.
- Westinghouse Electric Corporation

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Additional institutions are expected to be added to this list throughout the year.

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ENGINEERING MANPOWER BULLETIN

ENGINEERING MANPOWER BULLETIN

NUMBER 105
OCTOBER 1990

ISSN 0013-[illegible]

This 105th Engineering Manpower Bulletin considers current predictions of personnel shortages, growth potentials among specialties and industries, emerging technologies, globalism, and other trends that may affect engineering in the future.

Inquiries about the Engineering Manpower Commission's activities and reports are welcome. Contact R. A. Ellis, Director of Manpower Studies, American Association of Engineering Societies, (202) 296-2237.

PROSPECTS FOR ENGINEERING MANPOWER

What lies ahead for engineering manpower in the United States? In particular, will there be serious shortages of trained engineers early in the 21st Century? This *Bulletin* begins with a consideration of recent claims that we face scarcities of engineers. It then addresses other possible developments that could affect engineering in the future.

I. The Question of Shortages

For the last couple of years, the media have been full of predictions that the U.S. faces serious scarcities of engineers and other scientific and technical workers. This extract from a story in a small city newspaper is typical: "The United States could experience a shortage of 750,000 scientists and engineers by the year 2000, according to a 1989 study by the Women's College Coalition. . ." (Joy, 1990).

Table 1 shows how this news item can be traced to work done by the Division of Policy Research and Analysis (PRA) at the National Science Foundation (NSF). These analyses from NSF/PRA are the source of most of the shortage estimates now in circulation. None of this NSF work has been formally published, but several versions of these studies of potential scarcities of scientists and engineers have been circulated as "working drafts" (NSF, 1988a, 1989a, 1990). Estimates of the size and timing of the scarcities have varied from one draft to the next. The most recent version says that "The U.S. will have a cumulative shortfall of 540,000 [people with bachelor's degrees in the natural sciences or engineering] by 2000 and 675,000 by 2006, when compared to constant production at the 1984-86 average."

NSF/PRA states that what it calls a "shortfall" does not translate into a "shortage" unless the demand for these skills exceeds the supply. The agency also notes that it did not measure demand, but instead used the average production of natural science and engineering degrees during 1984-86 as "a proxy for demand." The shortfall measured by the Foundation is simply the cumulative difference between the numbers of natural science and engineering bachelor's degrees that are anticipated in the future and the number of those degrees that was reached when production was at record levels in the mid-1980's.

NSF/PRA also points out that "many [natural science and engineering] graduates use their skills productively in occupations not officially counted as scientists or engineers." This accounts for the fact that of the predicted scarcity in 2006 of 675,000 graduates, only 275,000 would actually have engineering degrees. Most users of the working papers have missed this point, leading readers to assume that the predicted shortfall of engineers is substantially larger than actually is the case. In the labor force, engineers greatly outnumber scientists of all types (see Table 2). Engineers make up a comparatively small share of the NSF/PRA shortfall estimates because those forecasts deal with the production of *all* bachelor-level college graduates with natural science and engineering degrees—and those degrees are earned not just by potential scientists and engineers but also by substantial numbers of other people, such as secondary school teachers and students interested in medical careers.

These predictions of scarcities of scientists and engineers are being criticized on a number of grounds. Fechter (1990) notes that the failure to formally publish the NSF papers may have led to a "lack of familiarity with the nature and structure of the PRA model," and has inhibited peer review. He also points out that the working papers "ignore the important issue of uncertainty and [produce] only one set of projections," albeit with varying results depending on which version of the papers the reader may

Table 1
THE ORIGINS OF A NEWSPAPER STORY ABOUT FUTURE SHORTAGES OF ENGINEERS: FROM THE NATIONAL SCIENCE FOUNDATION TO THE FREDERICK, MARYLAND *POST*

Source	Statement	Attribution
Unpublished working draft papers by the Division of Policy Research & Analysis (PRA), National Science Foundation, 1988-1990	Cumulative shortfall of 540,000 people with bachelor's degrees in the natural sciences or engineering by the year 2000; shortfall will reach 675,000 by the year 2006	Not Applicable (original source)
Interim report of the Congressionally-chartered Task Force on Women, Minorities, and the Handicapped in Science and Technology (1988)	By 2010, we could suffer a shortfall of as many as 560,000 science and engineering professionals	Not stated in the report, but based on one of the early draft papers from PRA/NSF
News story in the *Chronicle of Higher Education*, 1988	Shortfall of 560,000 scientists and engineers by 2010	Pre-publication announcement of the Task Force findings
Press release, Women's College Coalition, 1989	Net shortfall of approximately 750,000 scientists and engineers by the year 2000	Not stated, but taken from the *Chronicle*
News story, *Frederick (Maryland) Post*, 1990	Shortage of 750,000 scientists and engineers by the year 2000	Women's College Coalition

Note: see text and accompanying bibliography for formal citations of these materials.

Table 2
NUMBERS OF WORKERS IN OCCUPATIONS USUALLY CALLING FOR SCIENTIFIC OR TECHNICAL BACHELOR'S DEGREES (1988)
(In thousands. Source: BLS Current Population Surveys*)

Occupation	Number of Workers
Engineering	1.805.000
Mathematical & Computer Sciences	732.000
Natural Scientists	395.000
Cumulative Subtotal	2.932.000
College & University Teachers*	472.000
Secondary School Teachers*	400.000
Cumulative Total	3.804.000

* Current Population Survey (CPS) data reported in Betty M. Vetter. "Professional Women and Minorities: A Manpower Data Resource Service," Eighth Edition (Washington, D.C.: Commission on Professionals in Science and Technology, December, 1989), Table 4-7, pp. 92-93. CPS statistics are based on self-reported occupations of respondents to household surveys, and produce somewhat higher estimates of the numbers of engineers than some other sources (such as surveys of employers). The figure for science and engineering faculty was taken from Table 5-14 on p. 128 of Vetter. The figure for secondary school teachers was arbitrarily set at roughly one-third of the CPS total for all secondary teachers, by the author's judgement.

have seen. "Practitioners of the art of simulation modelling," he says, "are aware of the limitations of an activity which, in earlier times, relied on the entrails of a chicken as a decisionmaking variable. . . Such practitioners often undertake sensitivity analyses and provide a range of projections to underscore the uncertainty associated with their assessments. . . [F]ailure to acknowledge uncertainty can be pernicious, in that it can seduce the unsuspecting user into believing that the results are more robust than they actually are . . ."

Fechter also identifies a number of serious methodological weaknesses in the NSF/PRA approach. He refers to "the tautological supply relationship postulated by the model," and notes that the benchmarks used to judge the magnitude of the "shortfall" of the projected production of graduates are all-time historical peaks in the generation of these degrees (and thus likely to be biased on the high side as reasonable expected values for longer-run outcomes). He points out that the working drafts do not allow for the countervailing market responses that would be expected to occur if these types of large imbalances between supply and demand for technical services were to persist for extended periods of time.

Other criticisms focus on broader aspects of the shortage arguments. Disario (1990) takes a historical perspective: despite regular claims of shortages of engineers ever since the end of World War II, "the growth of the engineering population has far exceeded the growth in the U.S. population and has exceeded the growth in GNP." He also notes that, in general, engineering salaries have not outpaced inflation. And Rivers (1989) argues that the very notion of general shortages makes no theoretical sense. "From an economics point of view," he says, "there can be no such thing as a shortage in the long run." Along with Disario, Rivers is reminding us that actual shortages should result in increases in the constant-dollar price of engineering services—and these have not occured, despite the fact that we are already well into a long-feared decline in the production of new graduates that is due at least in part to substantial drops in U.S. birth rates during the 1960's and 1970's (EMC, May, 1990 and July, 1990; see also Ellis, 1990). Indeed, even while the output of new engineering graduates is dropping, the total population of engineers is still growing, and will continue to increase even under the shortfall conditions postulated by NSF/PRA (Fechter, *op cit.*).

Finally, NSF's shortfall forecasts make no allowance for changes in the economic outlook—which seems increasingly recessionary at this writing (late September, 1990). Variations in this factor are crucial: a poorly performing economy could wipe out all of the engineering positions implied by the shortfall forecasts (see below). The scarcity predictions also seem to fly in the face of numerous reports of defense-related layoffs at engineering employers throughout the nation, including Electric Boat, GE Aerospace, Grumman, Hughes Aircraft, Lockheed, McDonnell Douglas, Northrop, Sikorsky, and others. Current layoffs may not mean much, however, as predictors of the future. The experience of the 1970's demonstrates that it is quite possible for a decade to begin with a weak marketplace for engineering skills and end with record levels of employment.

Even if there were no difficulties with the NSF/PRA working papers, problems of distortions of the Foundation's work as it has been disseminated still remain. Table 1 illustrates this process. Crucial caveats noted by NSF have been overlooked as the writers of scarcity stories become more removed from the original source. In particular, the press reports have not observed the distinction between a shortfall of natural science and engineering graduates, which is what NFS has addressed, and a shortage of working scientists and engineers, which is what the media stories are reporting. There are also unexplainable shifts in the size of the shortfall numbers and their effective dates; these may be due to the existence of many versions of the NSF/PRA draft papers, with wide variations in their statements of the magnitude and timing of the predicted scarcities.

Where does all this leave us? It seems clear that there are ample reasons for skepticism with respect to predictions in the media of very dramatic shortages of scientists and engineers. Similar claims have been made for years without materializing. The current predictions can be traced to work that is questionable at best, and in addition the forecasts have been distorted during the process of dissemination in the press. Does this mean that there are no reasons to be concerned about the future supply of scientific and technical workers? Not at all—but all this attention on the expected magnitude of a possible future problem strikes us as evasive. It places a manpower supply cart in front of an economic and educational horse. It does serve to focus some attention on national scientific and technical manpower requirements, but the scarcity predictions may be an exaggeration of our situation, and exaggerations do us no particular service. They undermine the general credibility of research on issues of scientific and technical manpower. They distract attention from the underlying issues, most of them much more immediate, that caused interest in these forecasts in the first place:

- All observers of the scientific and engineering manpower scene agree that there are legitimate concerns about the supply of people with doctoral degrees. Such persons make up a relatively small part of the technical work force—only about six to seven percent of all engineers have Ph.D's—so scarcities of these workers do not have much impact on the outlook for engineering manpower. However, the availability of doctoral-level engineers is a critical question for university faculties and is also a significant concern for engineering-intensive research organizations like NASA. There are also reasons to expect that engineers will require more advanced education in the future (see below).
- We do not need to expect major national shortages in order to know that during the next few years, there will be further declines in the number of new engineering graduates. Companies that recruit heavily from these pools of graduates can expect competition for the services of young engineers to become more intense, assuming that other factors (like the economic outlook) remain stable.
- Whether shortages materialize or not, the findings of *Workforce 2000* (Johnson, 1987) still apply: the composition of the U.S. labor force is changing, and participation by women and minority groups in engineering must continue to expand. The alternative is dependence on a steadily diminish-

Table 3
ENGINEERING EMPLOYMENT ESTIMATES FOR 1988 AND PROJECTIONS FOR 2000
(in thousands. Source: U.S. Bureau of Labor Statistics)*

Employment Group	Estimated 1988.	2000 Alternatives: Low:	Moderate:	High:	Percent Change (Moderate Growth)
All Occupations	107,777	116,777	124,897	132,091	+16%
All Engineers	1,379	1,590	1,724	1,893	+25
By Selected Specialties:					
Aerospace	76	78	85	98	+12
Chemical	48	51	56	61	+17
Civil	180	200	213	229	+18
Electrical	431	554	604	664	+40
Industrial	132	142	155	171	+17
Mechanical	221	244	265	290	+20
By Selected Industries:					
All Manufacturing	715	750	833	931	+17
Aerospace*	155	167	185	218	+19
Electrical/Electronic*	266	285	321	356	+21
Fabricated Metal Prod.	23	22	24	26	+4
Instruments	51	61	68	74	+33
Non-Electric Machinery*	58	57	63	67	+9
Other Transp. Equipmt.*	44	41	45	50	+2
Petrochemical*	72	70	77	84	+7
Construction	23	26	28	30	+22
Communications	32	39	42	45	+31
Government	185	205	211	223	+14
All Services	306	432	463	505	+51
Business (inc. R&D)	121	190	203	222	+68
Engrg. & Arch. Svces.	155	202	218	239	+41
Trade/Finance/Insurance	43	54	58	62	+35
Utilities	40	49	52	58	+30

Source: Bureau of Labor Statistics printouts from the industry-occupation matrix (current version released October 1989). Additional information on this model was provided in the previous bulletin in this series (Dershowitz, 1990). These data are based on employer surveys and are more conservative than are the household survey-based numbers in Table 2. Similar but less detailed information is available in "Outlook 2000" (Washington, D.C.: Department of Labor, April 1990), pp. 50-52. This latter source adds self-employed persons and family farm workers to the numbers of wage-earners and salaried employees reported above. The "aerospace" industry group is formed by combining BLS data for the "aircraft and parts" and "guided missiles and space vehicles" subgroups. The remaining transportation equipment workers—motor vehicles, shipbuilding, and others—are grouped as "other transportation equipment." The "office, computing, and accounting machines" industry subgroup is moved from the "non-electric machinery" category to the "electrical/electronic equipment" group. The "petrochemical" industry class is formed from the combination of oil and gas extraction, chemicals and allied products (including drugs), and petroleum refining categories in the BLS data. Industry categories used here are not mutually exclusive: some, but not all, of the petrochemical components are also included in the "all manufacturing" summary group.

ing pool of talent. As Harold Hodgkinson has put it, ". . .the future. . . consists of an increase in Hispanic and black youth, and a decline among whites" (Commission on Professionals in Science and Technology, 1988).

- Whether shortages materialize or not, the need for improved math and science skills for U.S. school children remains obvious. This problem seems universal: employers tell us that they are experiencing as many difficulties finding and retaining qualified supporting technical workers as in recruiting more senior scientists or engineers. Improving science and math education has become the single paramount public affairs priority for the nation's engineering societies, who are now organizing to place 100,000 volunteers into American schools (AAES, 1990).
- It is in the national interest to make effective utilization of the existing supply of engineers. There is a large pool of trained workers: the annual output of bachelor's degrees in engineering doubled between 1975 and 1985. More emphasis on continuing education and inservice training is needed to ensure that these engineers remain productive, especially if we fear future shortages.

Engineers themselves react to claims of shortages in very different ways. Some seem pleased to find themselves in a profession that is highly valued and in demand, while others suspect that claims of shortages are simply devices used to encourage increases in the supply of engineers in order to keep down the price of their services. From the perspective of the national interests of the U.S., there may be no such thing as too many people with engineering skills. Nevertheless, it is one thing to say that the society needs engineers: it is quite another to come up with engineering jobs.

II. Other Predictors of Employment Trends: The BLS Data

A different look at the near-term future of engineering is provided by the data on engineers in the current version of the U.S. Bureau of Labor Statistics' (BLS) industry-occupation matrix, summarized in Table 3. It should be noted that the general growth rates anticipated by BLS for engineering employment are well in line with very long-range historical trends for the profession (EMC, May, 1990). These statistics utilize relatively stringent definitions of the term "engineer." They are based on employer data and do not count self-employed workers, nor do they include persons who may think of themselves as engineers but who are regarded by employers as something else, such as many engineering managers.

The most interesting feature of the BLS data is that, unlike other projections, they are available in some detail, for particular engineering specialties, particular types of industrial sectors, and combinations of specialty and sector (for example, electrical engineers working for manufacturers of electronic components). In other words, these data suggest where growth could occur.

Among the specialties, electrical and electronic engineering is expected to be the fastest growing engineering discipline between now and the turn of the century, while aerospace engineering is expected to grow only moderately. This is not a new prediction.

for at least five years, the Bureau has anticipated slowdowns for aerospace engineers from the peaks reached during the early years of the Carter-Reagan defense buildup.

Among industries, the strong sectors for engineering employment are in the services categories, especially in general business services (which include R&D laboratories) and in architectural and engineering services firms. The weak sectors are in manufacturing, particularly in more traditional fields like fabricated metal products, non-electric machinery, and automobiles.

The Bureau's employment forecasts include allowances for many detailed trends affecting both occupations and industries. The following extracts provide a flavor; readers are referred to the original source (BLS, 1990) for much more information:

- ". . .a general assumption of higher productivity growth than in the past. . . is partly based on a strong increase in investment spending for capital equipment, particularly for high-technology equipment such as computer-controlled production systems and automatic or robotic factory equipment. The "just-in-time" inventory method, assisted by computer control, was also assumed to become more widespread. The computer was assumed to play an increasing role in offices as well as in factories. . . It was also assumed that industries and government would continue to increase their purchases of services, contracting out for a wide variety of activities such as building maintenance, temporary help, legal and other professional services. . ."
- "Growth [is] projected for new factory construction. Modernization of existing facilities will also be prevalent. . . Increased demand for sewage treatment plants and waste disposal facilities was assumed. . . Replacement of aging bridges and highways will lead to continued growth of road construction. . . A slow growth in auto purchases reflects a projected slowdown in the growth of the driving-age population. . ."

The BLS forecasts also allow for varying economic conditions by their use of separate low-growth, moderate-growth, and high-growth assumptions; in particular, "the low-growth economy is characterized by much higher unemployment rates, higher inflation, continually increasing deficits in both [the] Federal [budget] and foreign trade, much lower growth in productivity, and deeper swings in the business cycle." The potential impact of these recessionary developments on engineering employment is measured by the difference between the "low" and "moderate" statistics in Table 3. Similarly, the "high growth" projection suggests the employment implications of a relatively strong U.S. economy during the 1990's.

III. Emerging Technologies

The employment of engineers is driven by developments in science and technology. In the previous bulletin in this series, Dershowitz (1990) took note of a list of emerging technologies that can affect engineering in the future. Table 4 provides more detailed information about these trends.

Here, as elsewhere, forecasters can disagree. For example, the Department of Commerce believes that high definition television (HDTV) may be commercially significant by the year 2000 (Technology Administration, 1990), while the Department of Labor says that the "impact of high definition TV will not be felt in this century," at least on employment (BLS, 1990). In general, however, there seems to be a reasonable degree of consistency in the visions of technological developments put forth by these sources. In particular, the work by the Department of Commerce was informed by similar studies done for the Department of Defense (U.S. Congress, 1990).

A crucial question is *where* the development of these technologies will occur. "If current trends continue. . . before the year 2000, the United States could lag behind Japan in most emerging technologies and trail the EC [European Community] in several of them" (Secretary of Commerce Robert Mosbacher, in the introduction to Technology Administration, *op. cit.*).

Engineering training is a critical element in the global race for preeminence in these technologies. Design engineering, manufacturing engineering, and the management of technology are identified as "three areas of particular importance" (Technology Administration, *op. cit.*):

- "Design engineering involves an appreciation of the importance of the relationship between design and productivity. Designing for manufacturability is very important. . . Furthermore, everyone connected to a product manufacturing line plays an important role in feeding information. . . back to the designers. These concepts are key ingredients in productivity improvement and are widely practiced particularly by Japan. . ."
- "Manufacturing engineering requires a full appreciation of the interdisciplinary nature of modern production methods. . . Decades ago, American engineering schools moved away from the curriculum of engineering practice into a curriculum of engineering sciences. . . current emphasis is on reversing this situation."
- "Management of technology requires a broadly based, generalist engineer/business graduate to create an integrated, interdisciplinary team approach to the manufacturing enterprise. The required skills span fields such as basic engineering concepts, business knowledge, systems analysis, operations research, and computing. . ."

Thus, engineering graduates may need to adapt to different roles and to master new kinds of skills to compete in the emerging technologies arena. At the same time, the new technologies will provide new tools for all engineers, especially those developments classed under the headings of "artificial intelligence" and "flexible computer-integrated manufacturing." The senior-level 21st Century engineer seems likely to be a high-level generalist supported by a broad range of computer-based intelligent systems, leading to substantial increases in standards of productivity and quality. Students of these trends suggest that many bachelor-level engineering graduates could take up career paths in management or finance, with the more traditional roles of engineering work reserved for those with master's degrees or other kinds of advanced professional training.

IV. Globalization and "World-Class Engineers"

"Forces are generating a need," according to a senior research executive with the Ford Motor Company, "for world-class engineers" (Guard, 1990). The use of such terminology by American engineering managers is a concession that the U.S. does not necessarily establish standards of the state of the art of the profession. Multinational corporations do not depend on the engineering talent of any one country. Substantial numbers of U.S. engineers work on projects abroad, just as substantial numbers of foreign engineers work here. Similarly, employers based in the U.S. draw on the skills of foreign engineers through contracts, subsidiaries, and other mechanisms for outsourcing, just as many foreign-based organizations employ U.S. engineers through their subsidiaries or other operations in this country. Wherever their country of origin or current location, the designers of "world-class" products and services could constitute a new and growing elite within the engineering profession.

To understand a world-wide engineering system, manpower information organized strictly along national lines is not adequate. Existing data on the international stock of engineering talent and on the flow of work among this pool of workers is limited to a few country-specific studies (for example, Jamison, 1989; Lynn, Piehler, and Zahray, 1988; Mintzes and Tash, 1984; NSF, 1986, 1988b, Nishigata, Nakanishi, and Hirano, 1989).

Table 4
EMERGING TECHNOLOGIES
(Source: Technology Administration, U.S. Department of Commerce, 1990)

1. POSSIBLE COMMERCIAL IMPACT BY THE YEAR 2000:	
A. Materials	*Advanced materials:* structural and functional ceramics, ceramic and metal matrix composites, intermetallic and lightweight alloys, advanced polymers, surface-modified materials, diamond thin films, membranes, and biomaterials. Applications may include improved strength, resistance to various type of degradations, materials with "designed in" properties.
	Superconductors: high-temperature ceramic conductors, advanced low-temperature conductors. Effects include major cost reductions, powerful magnets for uses such as levitated trains, many electric power and transmission applications, as well as utilization in computers and partical accelerators.
B. Electronics; Information Systems	*Advanced semiconductor devices:* silicon and gallium arsenide devices, ultra large-scale integration, improved memory chips, X-ray lithography. Such developments will improve speed, operating frequencies, densities, functions, and costs of all electronic devices.
	Digital imaging: high definition systems, HDTV, large displays, data compression, image processing. Applications in electronics, computers, process control and inspection, medical diagnostics, consumer electronics, telecommunications, broadcast TV, satellite broadcasts, data storage, defense systems.
	High-density data storage: both magnetic and magneto-optical storage. Improvements in information densities, access times, reliability of access, and resistance to degradation have applications ranging from archival storage to consumer cameras.
	High-performance computing: modular/transportable software, numerical simulation, neural networks. Applications include weather forecasting, hydrodynamics and aerodynamics, weapons research, prototyping of products and facilities, high energy physics, and general R&D in all fields.
	Optoelectronics: integrated optical circuitry, optical fibers, optical computing, solid-state lasers, optical sensors. Developments will improve the capacity, signal quality, resistance to interference, and speed of information systems of all types.
C. Manufacturing	*Artificial intelligence:* intelligent machines, intelligence processing of materials and chemicals, expert systems. Applications include more intelligent machine tools, robots, construction equipment; analysis of medical tests or symptoms; computer-aided design; signal and image processing.
	Flexible computer-integrated manufacturing: computer-aided design, engineering, logistics support, manufacturing; flexible manufacturing systems; product data exchange specifications; control architectures; adaptive-process control. Such systems are viewed as crucial steps in ensuring the competitiveness of automotive, construction, appliance, and many other industries.
	Sensors: active/passive sensors, feedback and process control, nondestructive evaluation, industrial and atmospheric environmental monitoring and control. Impact on all types of continuous process industries such as materials, foods and beverages, pharmaceuticals, chemicals, smelting, waste management, and more.
D. Life Sciences:	*Biotechnology:* bioprocessing, drug design, genetic engineering, bioelectronics. Applications in pharmaceuticals, foods, flavors, fragrances, agrichemicals, fuels, pollution abatement.
	Medical devices and diagnostics: cellular-level sensors, medical imaging, in-vitro and in-vivo analysis, targeted pharmaceuticals, fiber optic probes. Developments can lead to the capability to detect and understand defects at a cellular level; opportunity to use biomolecules as sensitive probes; reduced trauma in diagnosis and treatment.
2. EXAMPLES OF EXISTING TECHNOLOGIES THAT MAY EXPAND OR CHANGE BY THE YEAR 2000:	
	Building technology: advances are anticipated in flexible/modular manufacturing, intelligent buildings, facilities diagnosis, construction quality assurance, use of new materials, and earthquake and geotechnical engineering.
	Chemical catalysts: advances in areas such as computer modeling of complex reactions and design at the molecular level are expected to support the manufacture of new materials, reduce costs of existing products, and increase yields.
	Energy: new insulating materials, advanced instrumentation and sensors, and use of modern computing and communication technologies are expected to help the nation to move toward more environmentally acceptable and economically viable generation, control, and transmission systems for electric power. Efforts to move toward "clean and ultra-safe nuclear power generation" are envisioned.
	Fire safety: applications are anticipated based on advances in polymer thermal degradation, advanced sensing and extinguishment techniques, and risk prediction, management, and control.
	Microwave technology: new applications for components and antennas include areas such as robot vision, collision avoidance, and wind shear detection.
	Radiation processing: accelerators and radionuclide sources are being used in sterilization of foods and materials, curing of polymers, radiation-induced catalysis, and waste processing. Entirely new products with unique mechanical, electrical, and temperature resistance properties are possible.
3. AN EXAMPLE OF ADDITIONAL TECHNOLOGIES *NOT* EXPECTED TO HAVE COMMERCIAL IMPACT UNTIL AFTER THE YEAR 2000:	
	Nanotechnology—applications of molecular manipulation, nanolithography, and molecular electronics to produce extremely dense electronics, new orders of mechanical miniaturization, custom-designed materials, and novel pharmaceuticals.

Most of this material deals only with France, Japan, the United Kingdom, the U.S., and West Germany. Very limited data is available on the USSR. EMC itself has access to information from Canada and Australia. A thorough search of academic holdings will be likely to turn up additional materials, but at this writing we have not been able to identify comparative sources of engineering manpower data for such locations as Scandinavia, Italy, Eastern Europe, the Middle East, Latin America, China, India, and "Asian Rim" countries like Taiwan and Korea. Some material has also been summarized in general reports (National Science Board, 1989; NSF, 1989b).

No source known to us provides what is really needed: comparable counts, for all of the world's significant industrial societies, of the number of engineers in work forces and of the numbers of degrees being awarded. Those data would at least provide a start. In addition, information is also needed on such phenomena as migration, "brain drains," and developments like the generation of software by colleagues located halfway around the globe, communicating over voice and data networks via fiber-optic telephone lines. Definitional problems must be resolved to assemble this type of information. In addition to the obvious need to equate degrees and professional statuses which are

defined in differing ways from one culture to the next, there are also questions as to the status of the *sources* of engineering work. That is, while there is still a tendency to think of employers as either "domestic" or "foreign," increasingly most of them are "multinational," a term that transcends these older labels.

Lacking data, our picture of the emerging global engineering system is unclear. What is clear is that U.S. engineers now face new kinds of competition from people who do not always share the assumptions and expectations about education, work, and success that have been typical in this country. One close observer of these trends calls attention to the fact that "the reality we see in Asia is a 56 to 64 hour week for engineers. The work ethic does make a difference. . ." (Cannon, 1990). Others have noted that few U.S. engineers have foreign language skills or the kinds of related bicultural experience that can be helpful in coping with multinational employment markets.

If there is a single issue that expresses the concern of Americans about our ability to cope in the future with the global marketplace, that issue is the quality of U.S. education and the ability of the children now in our schools to survive in a world where they must compete not just with other U.S. citizens but with bright, well-educated, ambitious, hard-working people from Asia, Europe, and the rest of the world. The views of the science and technology community on this problem are well known:

- "The way the science is marketed to our young people is all wrong. . . Although U.S. students believe they are good at math, their performance on international standardized tests says otherwise. . . We American adults, wanting things better for our children, may inadvertently have pushed or pulled them away from science by being too easy on them, by giving them everything without their having to work for it. Perhaps the nation has become too affluent, so that our children became accustomed to instant gratification, without much work. . ." (Teich, 1990).
- "The fundamental problem with the K-6 level is that the teachers themselves do not understand any science. They have not studied science; they are frightened by it. . . What we have is a fundamentally defective system that filters out people in a way that negates the need for the SAT test" (Aldridge, 1990).

Opinions about the schools are just as scathing among other observers outside the science and engineering community:

- "The U.S. is becoming a nation of badly educated, ill-informed nincompoops" (Utne, 1990).
- ". . .a growing population of students. . . don't care about learning. Their apathy and indifference is gradually eroding my function and purpose as an educator. . . There's a prevalent and disturbing attitude among many kids that teachers—or any other adults—can't teach them anything: the 'know-it-all' factor" (Collins, 1990).

Older generations have regularly assumed that the young are fatally flawed, a fact that has not escaped some observers of education. "Whatever its lofty motives, the education reform movement in practice has proven an orgy of blaming the victims—teachers and students alike—particularly those in the most beleagered urban schools. Strikingly absent from the debate are common sense and empathy" (Freedman, 1990).

Most of us believe the U.S. must generate its share of "world-class engineers" to maintain its accustomed standard of living. Without an adequate technological work force, "America's economic strength, security, and quality of life are threatened" (Task Force on Women, Minorities, and the Handicapped in Science and Technology, op. cit.). Certainly excellence in education, in terms of both schools and the quantity and quality of graduates, is a prerequisite for reaching these goals. But other factors are also critical: the costs of investment capital; the willingness of entrepreneurs to take on long-term risks; cultural barriers like the "NIH" (Not Invented Here) syndrome; and legal issues including trade, antitrust, intellectual property, and

This typo was corrected in a subsequent issue of the Bulletin.

product liability policies (Technology Administration, op. cit.). In thinking about the future, manpower issues, such as questions of the education of high technology workers, are not the only matters that will make a difference.

V. Some Potential Scenarios

Looking over these various possibilities and potential developments, a number of futurist scenarios can be suggested. Some trends seem more enduring and stable than others, and can be treated as givens (at least for present purposes); others are much more uncertain, and variance in those factors will therefore affect which scenarios come to pass, if any:

- A stable trend is the globalization of economic efforts and continued growth in the influence of multinational corporations. Economic variables may affect the pace of this trend but seem unlikely to alter its general direction.
- The rate of increase in the employment of engineers, measured at ten-year intervals, has been fairly consistent for the last 50 years (EMC, May, 1990, op. cit.). Unless there are truly extraordinary developments in the 1990's (such as a world nuclear conflict, major epidemics, or a deep economic depression), the Bureau of Labor Statistics employment forecasts should be consistent with these long-run trends.
- On the other hand, the variations within the BLS forecasts for low, moderate, and high-growth economies are excellent examples of scenario elements that cannot be predicted today, and which therefore should be compared to see what alternatives may be in store for the profession.
- An issue that seems genuinely uncertain is the degree to which the U.S. may succeed in obtaining satisfactory results from its education system. Very ambitious goals have been proclaimed, but it is not at all clear that those goals will be attained.

Thus one can vary economic and educational assumptions, holding constant general employment trends and the movement toward globalization of enterprise, in order to consider the likely results in terms of the competitiveness of U.S. engineering and the potential strength of demand for additional engineering services. Like all attempts to gaze into crystal balls, this exercise is highly speculative. It cannot be pushed ahead very far in time—ten to fifteen years at most. And it is almost certain to be undone in actuality by events that cannot be forseen at all at this writing. Nevertheless, for planning purposes such exercises are better than doing nothing at all.

Table 5 summarizes a simple application of this approach. The economic variables have been reduced to a dichotomy defined by the BLS "low" and "high" growth economies. These extremes represent a predicted difference of over 300,000 engineering jobs in the year 2000 (see Table 3). Thus the success or lack thereof of efforts to deal with U.S. educational problems should have much to do with whether or not this gap can be made up (if it develops), or if it presents serious problems of underemployment (if efforts to improve education succeed but the economy performs poorly). The latter possibility is not a minor problem. Some countries have found it necessary to create Youth Ministries or to encourage emigration when their educational capacities outstripped their economic capabilities.

Using the oversimplified double dichotomy in Table 5, four alternative archetypes for the future of engineering emerge. One of these is the one for which policymakers will strive. In this version of the future, success in both education and economics has kept the U.S. competitive, raising reasonable possibilities that there could indeed be some sort of shortage of engineers. At the opposite extreme, the scenario in which the U.S. fails in both educational and economic terms comes uncomfortably close to suggesting the nightmare visions of "cyberpunk" science fiction: all we need to add to it is massive pollution and urban decay

In the middle are two more ambiguous possibilities. One has already been noted above: an alternative where our educational efforts have succeeded but our economic endeavors have not, leading to the likelihood of attracting substantial numbers of young people to careers for which there are insufficient jobs. In this eventuality, it seems reasonable to speculate about the possibilities of emigration as an alternative for U.S. engineers (as it is in other developed nations when economies weaken), and to point out that if oversupplies of scientific and technical talent develop, the price of those services should fall.

The last alternative is one where the U.S. economy has prospered for at least the decade of the 1990's, but our educational efforts have failed. This scenario is similar in fundamental ways to the present situation: we are emerging from a decade of relative prosperity, and there is a great deal of current dissatisfaction with the state of our schools. This alternative describes a short-run future in which the U.S. has continued to put off its problems without managing to solve them; it is an alternative of delayed resolution and seems inherently unstable, for it is difficult to imagine how the nation could compete over the long run in the global race for technology without an adequate work force of scientists and engineers.

The tentative nature of these models cannot be over-emphasized. All sorts of other factors may come into play, overriding the simple assumptions examined in Table 5. For example, if the U.S. increases its use of people with engineering training in management and financial roles, as has happened in Japan, this expansion of demand would help to absorb any excess production of graduates in the low-growth models, and would add to the possibilities of scarcities of trained people in the high-growth alternatives.

The only sure aspect of the future, if the experience of forecasting is any guide, is that there will be surprises. On the political and economic side, an example of such a development would be the emergence of China or the USSR as a serious player in the race for global technology. Both nations have considerable technical capacity layered onto what are basically third world economies. If nations like Taiwan and Korea can become formidable forces in multinational markets, so could these—if, as may be unlikely, they can overcome problems caused by decades of poor political and economic management. Technical surprises are harder to identify, in part because proprietary interests are at stake, but surely some will emerge.

This review of future possibilities suggests that the current preoccupation of the media with the magnitude of a possible shortage of scientific and technical workers considers only one of many serious questions that face engineering. The real challenges are economic and educational. The coming decade may provide a crucial test of our ability to deal with these issues.

—R. A. Ellis

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Table 5
IMPLICATIONS OF VARYING ECONOMIC AND EDUCATIONAL ASSUMPTIONS FOR U.S. ENGINEERING IN THE EARLY 21ST CENTURY*

Educational Reform in the 1990's:	Economic Results of the 1990's: High Growth:	Economic Results of the 1990's: Low Growth:
Schools perceived as Performing Well:	POLICYMAKERS' CHOICE: U.S. is competitive in the global race for technology. Possible shortages of high tech workers could raise the price of their services.	NOT ENOUGH WORK TO DO: U.S. still behind in the global competition. Excess production of engineers encourages lower salaries, emigration of U.S. workers.
Schools Perceived as Performing Badly:	MORE OF THE SAME: Fears persist that U.S. may not be competitive. Poor quality of work force leads to increased use of foreign engineers, outsourcing.	A SYSTEM IN DECLINE: U.S. losing race for global technology. Increasing general importance of all foreign labor markets. "Crisis mentality."

* Credit should be given to the late Herman Kahn and his colleagues at the RAND Corporation and the Hudson Institute for developing this method and style for the presentation of forecasting models using the scenario method. See in particular Kahn's "On Thermonuclear War" (1961).

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The Engineering Manpower Commission, now entering its 40th year of service to the profession and the nation, is composed of 32 volunteers who represent industry, government, academia, and the professional engineering societies. A new associate program for industry and other institutional affiliates was begun this year. As of June 1, these associate members included:

Patron Sustaining Associates:
General Electric Foundation
National Action Council for Minorities in Engineering

Senior Sustaining Associates:
Amoco Foundation

Sustaining Associates:
America Institute of Chemical Engineers
Eastman Kodak Company
E. I. duPont de Nemours & Company
Exxon
Procter & Gamble Co.
Westinghouse Electric Corporation

Contributing Associates:
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Society for Mining, Metallurgy, and Exploration, Inc.
Deere & Company

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An abridged version of the *Special Industry Report*. Details for salary differences by highest degree held are not included: tabulations are added on engineering compensation in local, state and federal government agencies.

member price: $59.50 non-member price: $97.00

SALARIES OF ENGINEERS IN EDUCATION 1990

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Society of Women Engineers (SWE)

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Federation of Materials Societies (FMS)
National Action Council for Minorities in Engineering (NACME)

Regional Societies:
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Engineering Society of Detroit (ESD)
Engineers' Society of Western Pennsylvania (ESWP)
Engineers' Society of Tulsa (EST)
Western Society of Engineers (WSE)

Bibliography on Supply and Demand for Scientists and Engineers

(NOTE: originally prepared as a part of a submission 4/19/91 to the Division of Social and Economic Science, National Science Foundation, in response to an NSF announcement seeking bids to conduct research on methods to estimate supplies and demands of U.S. scientists and engineers, submitted by the American Association of Engineering Societies in cooperation with the Commission on Professionals in Science and Technology and the Institute for Economic Analysis at New York University.)

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– *National Science Foundation*
April, 1990

"In the year 2000, considering demographic changes, American colleges will produce about 16,000 fewer engineering graduates than in 1983, leaving more jobs available than qualified employees to fill them."

– *Engineering Times*
July, 1988

. . . or SURPLUS?

"The decade of the 90's will produce an annual surplus of 10 to 15 thousand engineers per year."

– *Electronic Engineering Times*
July, 1990

"So-called shortages usually are not shortages at all, but more often reflect insufficient applicant numbers at wages employers are willing to pay."

– *"Scientist and Engineer Supply and Demand"*
1990

ENGINEERS IN AMERICA'S FUTURE:

Wednesday, September 11, 1991

8:00 a.m. - noon — **REGISTRATION**

10:00 - 10:30 a.m. — **OPENING PLENARY SESSION**
Welcome: Donald C. Brown, Chairman, Engineering Manpower Commission
Opening Remarks: Lewis G. Grimm, Chairman, EMC Conference Committee

10:30 a.m. - noon — **STATISTICAL BACKGROUND: CURRENT ESTIMATES AND PROJECTIONS**
Representatives from agencies and organizations that publish statistical information on the engineering workforce will discuss their sources of information, statistical techniques, views on the shortage and surplus issue, how and why their findings are different than those of other organizations, and the implications of their findings on industry, academia, government, professional engineering societies and America's ability to compete in world markets.
Moderator: Betty M. Vetter, Executive Director, Commission on Professionals in Science and Technology
Panelists: Thomas A. Amirault, Labor Economist, Bureau of Labor Statistics, U.S. Department of Labor
Myles G. Boylan, Policy Analyst, Division of Policy Research and Analysis, National Science Foundation
Susan C. Kemnitzer, Deputy Director, Division of Engineering Infrastructure Development, National Science Foundation
Malcolm S. Cohen, Project Director, Institute of Labor and Industrial Relations, University of Michigan at Ann Arbor

Noon - 1:40 p.m. — **OPENING LUNCHEON AND KEYNOTE ADDRESS**
Introduction: Donald C. Brown, EMC Chairman
Invited Speaker: The Honorable Lynn M. Martin, Secretary, U.S. Department of Labor

1:40 - 3:00 p.m. — **FUTURE SCENARIOS: IMPACT OF DEMOGRAPHIC, ECONOMIC AND TECHNOLOGICAL CHANGES ON ENGINEERING SUPPLY AND DEMAND**
Speakers will discuss the effects of demographic trends on the availability of engineering talent and the implications of those trends on public and private policymakers; the impact of major economic variables, including America's trade balance and government spending policies, on employment for engineers; the impact of federal monetary policies and changes in defense spending on employment opportunities for electrical, electronics and computer engineers; and the effects of changes in technology on future requirements for engineers.
Moderator: George Campbell, Jr., President, National Action Council for Minorities in Engineering, Inc.
Panelists: John W. Porter, Superintendent, Detroit Board of Education
Robert A. Rivers, Aircom Inc.
Dennis A. Swyt, Chief, Precision Engineering Division, Center for Manufacturing Engineering, National Institute of Standards and Technology
Keith Wilkinson, Program Analyst, Science Resources Studies Division, National Science Foundation

3:00 - 3:20 p.m. — **BREAK**

3:20 - 4:40 p.m. — **CONGRESSIONAL PERSPECTIVES**
Key members of the U.S. Congress will discuss the current and projected strengths and weaknesses of America's engineering resources, the overall importance of engineers in America's ability to innovate and manage technological change, and the appropriate roles of business, academia, government and professional societies in coordinating efforts to alleviate shortages and surpluses in the engineering workforce.
Moderator: Albert A. Grant, Chairman, American Association of Engineering Societies
Panelists: *U.S. Senators and Representatives, to be announced*

4:40 p.m. — **ADJOURNMENT**

6:00 - 7:00 p.m. — **COCKTAIL AND HORS D'OEUVRES RECEPTION**

7:00 - 9:00 p.m. — **BANQUET AND RECOGNITION CEREMONY**

SHORTAGE or SURPLUS?

Thursday, September 12, 1991

8:00 a.m. - noon	**REGISTRATION**	
9:00 - noon	**EMPLOYER REQUIREMENTS** Spokespersons from major engineering employers will discuss one or more of the following: how their companies determine current and projected requirements for engineers; what kinds of products and services will offer their companies the greatest growth opportunities between now and 2000; how many and what kind of engineers will be needed to capitalize on these opportunities; the steps their companies are taking to meet their projected requirements for engineers and engineering managers; and the appropriate roles of industry, academia, government and professional engineering societies to redress imbalances in the engineering workforce.	
9:00 - 10:20 a.m.	**PART I: INDUSTRY**	
	Moderator:	F. Suzanne Jenniches, General Manager, Civil Systems Division, Westinghouse Electric Corp.
	Panelists:	Autos/Aerospace Carver C. Gayton, Corporate Director, College & University Relations, The Boeing Company Petrochemicals/Pharmaceuticals Robert K. Armstrong, Manager, Professional Staffing & Human Resources, E. I. du Pont deNemours & Company Computers/Telecommunications Ronald D. Schmid, Director, Technical Personnel Development, IBM Corporation Power/Utilities Orlando J. Ortega, Manager, Engineering & Construction, Southern California Edison Company
10:20 - 10:40 a.m.	**BREAK**	
10:40 a.m. - noon	**PART II: EDUCATION, GOVERNMENT, AND ENGINEERING SERVICE FIRMS**	
	Moderator:	Eleanor Baum, Dean, School of Engineering, The Cooper Union
	Panelists:	Engineering Deans Council Leroy S. Fletcher, Thomas A. Dietz Professor, Texas A&M University Federal Government Christopher Jehn, Assistant Secretary, Force Management and Personnel, U.S. Department of Defense Engineering Services Delon Hampton, President, Delon Hampton & Associates High Technology/Entrepreneurial Paul H. Rothe, Vice President, Creare, Inc.
Noon - 1:40 p.m.	**LUNCH AND CONFERENCE WRAP-UP** The speakers will discuss the major trends, issues, problems, concerns and recommendations identified by conference participants; their perspectives on the significance of current and projected shortages or surpluses in engineering labor markets, and the impact these will have on U.S. economic competitiveness and living standards; the actions that industry, academia, government and professional societies should be taking to alleviate workforce imbalances; and the type of statistical information needed to better anticipate these trends.	
	Introduction:	Lewis G. Grimm, EMC Conference Chairman
	Speakers:	Alan Fechter, Executive Director, Office of Scientific and Engineering Personnel, National Research Council Daryl E. Chubin, Project Director, Science, Education and Transportation Programs, Office of Technology Assessment
1:40 - 3:00 p.m.	**OPEN FORUM ON EMC PROGRAMS** (for EMC Associates, AAES Industry Affiliates and others) *Moderator:* Donald C. Brown, EMC Chairman	
3:00 p.m.	**ADJOURNMENT**	

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- Assess the reliability, validity and credibility of major sources of statistical information on current/projected supply and demand for engineers;
- Determine the probable impact of demographic, economic and technological trends on engineering supply and demand;
- Find out how major employers of engineers view current and projected labor markets and what steps they are taking to meet current and future requirements; and
- Identify appropriate remedial actions that can and should be taken by industry, academia, government and professional societies to alleviate current and projected shortages and surpluses.

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- Employers of Engineers
- Professional Engineering Society and Trade Association Members
- Members of Congress and their Staffs
- State and Federal Government Representatives
- Deans and Professors of Engineering Schools
- General and Trade Press
- Former/Current EMC Members
- AAES Industry Affiliates
- EMC Sustaining, Contributing or Academic Associates
- Anyone concerned with the supply and demand of engineers in the U.S.

ABOUT THE EMC

The Engineering Manpower Commission (EMC) has been a source of objective, timely data on the supply and demand for technological personnel since 1950. As a commission of the American Association of Engineering Societies (AAES), the EMC is composed of volunteers from professional engineering societies, academia, government and industry.

The EMC conducts annual surveys of industry and schools of engineering, monitors trends in the supply and demand for engineers, and produces annual reports on engineering enrollments, degrees and salaries. The EMC also produces the *Engineering Manpower Bulletin*, which assesses trends in the engineering workforce.

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HOTEL INFORMATION

Place: Loews L'Enfant Plaza Hotel
480 L'Enfant Plaza, SW
Washington, DC 20024
(202) 484-1000

Rate: $125 single/double occupancy + taxes

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Social scientist. More than 25 years of experience as a designer and director of research for public agencies, nonprofit organizations, professional associations, and corporations.

Education: B.A., with honors, 1965, social science, Fenn College. M.A., 1968, sociology, University of Chicago; Stouffer Fellow and full-time staff associate at the National Opinion Research Center (NORC), working principally on surveys of scientific manpower.

Position: Director of Manpower Studies, AAES, since 1985; responsible for all of the research and publications of the Engineering Manpower Commission (EMC). The Commissioners are volunteers drawn from professional engineering societies, industry, universities, and government. EMC has been a major source of information on the topic of scientific and technical workers since it was founded in 1950. It produces authoritative annual statistics on engineering enrollments, degrees, and salaries. It also publishes a series of eight bulletins a year on these topics and on such related issues as the supply of and demand for engineering services; the status of women and minority groups in the profession; and trends in the utilization of engineers.

EMC's research operations are unusually accurate, detailed, and rapidly executed. They are also very cost-effective.

Other Experience: design and direction of numerous local, national and international projects. Experienced in research on a wide range of topics, including all aspects of education; foreign and and domestic economic development; and surveys of occupations and professions. Clients have included many U.S. government agencies; the World Bank; the Development Centre of the OECD; the New York State Education Department; Merrill Lynch; and religious bodies. Expert with a wide range of research methods, including longitudinal and cross-national surveys. Experience throughout the United States and ten foreign nations.

Other Activities: President, Board of Trustees, Brunswick Public Library, 1986-1990; member, ACG/NJ (the Amateur Computer Group of New Jersey), since 1983. Active in various local civic and political organizations.

Mr. BOUCHER. Thank you very much, Mr. Ellis, and the appreciation is expressed from this subcommittee to all of the witnesses for their insightful testimony this morning.

The matters that you bring to us today are of great concern. If we do not have accurate information about the manpower supplies and accurate models by which to project future needs, then it's obviously very difficult for Congress to make informed decisions about how to apply other resources in addressing those problems. And so having accurate models is fundamental.

Now, I've heard each of these witnesses, to some greater or lesser extent, suggest problems with regard to the modeling and, in particular, NSF's database and projections, and so my first question to you is simply this. Is it possible, given the resources that the NSF presently has and is devoting to this effort, to construct appropriate models to implement the recommendations that have been forthcoming from the National Research Council and others, and if not, what level of resources do you think might be needed in order to meet that need?

Dr. Fechter, let's begin with you.

Dr. FECHTER. All right.

That's a curve ball you threw, not a soft lob pitch. I will say that—try to give some perspective to the question because I think it's not an easy one to answer well.

I clearly believe that we will need to do better on the projections modeling and that resources are required to do that. I also agree with my fellow panelists that the data systems that are available to do this work are important, also, and need to be kept up to snuff. Having said that, though, I am also aware of the fact that we live in a world of stringency when it comes to budgets, okay. And there is a trade-off that one has to consider between what one does and what one gives up. So if I were to say to you we need to spend a lot of money developing elaborate models that would be then used to give us these forecasts, it's very possible that the monies might come from the data base development, which is also very important in this process.

So there are trade-offs that need to be made, and I think the question has to be raised, how much is enough? Do we want a perfect product? It's like many people talk about policies that will attain zero pollution. It's almost impossible to think about sensible policies that will yield to that goal. While, similarly, I think we can't talk about solutions that will give us the perfect data base or the perfect models because I think that takes us well beyond the pale of what the resources are that we can spend for these.

Mr. BOUCHER. How about an acceptable data base and an acceptable model?

Dr. FECHTER. That's right; that's what we are looking for. And, I think there I can only give you some guidance in terms of my thinking about the question of what's the proper level of aggregation of points, that was just raised in the testimony. Well, there are a lot of us who would feel we want the ultimate disaggregation, and we should do every field and be able to prepare supply and demand estimates for every field in every occupation, for every region of the country, for every age group, for every degree level,

okay. If you built—if you tried to do all of that, you'd get into—zero pollution. That's the game of zero pollution, I think.

So one needs to think about what's proper in terms of aggregation of information to be able to deal with these issues. And in my opinion there are levels of aggregation that are appropriate—and this probably doesn't accord well with my colleague from the Manpower Commission, Dick Ellis—but, for example, my sense of aggregation would be fields where you have a surplus in one field as opposed to another field where there is a shortage. If those fields have what I call highly permeable membranes—lots of flow between them, people can move back and forth with ease—I believe we are dealing there with one field, not with two fields.

And so, if in fact, engineering disciplines, for many purposes, can be considered highly substitutable for one another in various functions. For some purposes the name of the game, then, is to aggregate. If, in fact, people with B.A.s in mathematics and physics can perform as engineers—and there is a lot of mobility that takes place between them and Bob Dauffenbach has documented that—then we ought to think about doing that. And in that regard, I think what the shortfalls effort did was correct. It was—it looked at natural scientists and engineers. This is a group of people who for many purposes can be considered in the aggregate because imbalances in one can be used to off-set other imbalances in others.

So some aggregation is necessary both in terms of what kind of data—at what level of aggregation do we want our data to be precise, and also at what level of aggregation do we want our models to be working at?

I'm afraid I can't give you a good answer as to what precisely that means in terms of dollars and cents and numbers. I think the right way to deal with that is, if you feel that you need information on these questions, you have to let the agencies responsible for this information know of your needs. Perhaps you may want to ask them to report these pieces of information to you on a regular basis. That certainly provides an incentive for these organizations to get about the business of allocating the resources in the right direction. The leverage that exists is the leverage of requiring information that you require to do your jobs, and I think if you specify that information correctly, they will come, as it said in the movie.

Mr. BOUCHER. Well, let me ask you this. Did you as a part—did the National Research Council, as a part of its study, look at the resource allocation within the NSF toward its data base and the development of its models? Is that one of the things that you examined?

Dr. FECHTER. I would—I will answer it, but I would defer to Bob Dauffenbach for a more definitive answer.

Mr. BOUCHER. All right. Dr. Dauffenbach?

Dr. DAUFFENBACH. The answer to the that is yes, and of course resource stringency has been one of the big problems. I think that—

Mr. BOUCHER. Would you elaborate a little bit on that?

Dr. DAUFFENBACH. I would.

When you look back at a lot of the problems that we had with the postcensal in the 1980s, they resulted from what I would call a

restricted sampling base. In other words, in order to get a large number of scientists and engineers in their survey, what they did is they went to the Census and they said, well, let's look very heavily at people who were showing up as scientists and engineers by their occupation in the Census. So there is a stratified sampling on that basis of occupation from the 1980 Census.

And dealing with that stratified basis of sampling, you have certain problems. You miss out on people who may have science and engineering training—who do have science and engineering training, but don't happen to be doing science and engineering at the time—working in other occupations. Management was included in the strata. A lot of scientists and engineers do management, but there are a lot of other occupations that scientists and engineers do.

To give you an example of the magnitude of that statistic, we know from other surveys that only 46 percent of bachelor's degree holders in engineering in this country are working anywhere in science and engineering occupations—only 46 percent. And that's a high number; that's the highest of bachelor's degree holders working in science and engineering of the science and engineering educational fields.

Mr. BOUCHER. Let me get you to address—and if you didn't look at this as a part of your study, just tell us that —

Dr. DAUFFENBACH. Okay.

Mr. BOUCHER.—but did you assess within the National Science Foundation their allocation of resources with respect to the development of models that could project shortfalls. And if you did not that's fine. Just tell us that. And maybe we're accessing the wrong data base to try and get that information.

Dr. DAUFFENBACH. It's absolutely—it's absolutely the data base to get that information. That doesn't mean you don't have to rely on other data sources too. I think that—

Mr. BOUCHER. Well, did you asses that as part of your study?

Dr. DAUFFENBACH. We assessed the amount of information —

Mr. BOUCHER. And what was your conclusion? Did your conclusion—

Dr. DAUFFENBACH. My conclusion is like I state here, I think even after the CNSTAT panel—I don't even think the CNSTAT panel worked this out very clearly—the sampling base—getting a sufficient sampling base—the costs of that have just not been addressed that fully. I mean they've got money to do about 150,000 sampling of college educated people. That's going to yield, by my calculations, around 30,000 cases, and 30,000 cases is not sufficient to answer questions about women and minorities, foreign nationals in our experienced work force. It's—

Mr. BOUCHER. Do you have an estimate of what a proper figure would be?

Dr. DAUFFENBACH. A minimum of three times that.

Mr. BOUCHER. Dr. Fechter would you like to—

Dr. FECHTER. I would simply want to observe the following that the charge of the committee, this Committee on National Statistics in this case, who did the study, was to focus on the statistical robustness of the information system that existed and most of the energy and effort went into that. There was some discussion of

what use would be made of this information, but the bulk of the effort was to—talking about improving the quality of the data system itself, for all uses basically. There was no attempt to think about or examine—

Mr. BOUCHER. What is the cost of that improvement?

Dr. FECHTER. No, they did not deal with that although it was clear to everybody that it was not—it was an expensive package. It was not a cheap package.

Mr. BOUCHER. And that the expense of that would exceed the resources that the NSF devotes to it presently?

Dr. FECHTER. Well, that's probably correct, but there was nothing in the report itself that talked about a particular dollar figure that should be spent. There were goals set in terms of the quality of the data, and whatever it would take to get those goals met would be what they would advocate spending. But I think there is a realization on the part of all that trade-offs have to be made because of constraints that exist in budgets.

Mr. BOUCHER. Can you tell us then that some increase in funding would be necessary for this function?

Dr. FECHTER. Absolutely.

Mr. BOUCHER. Dr. Dauffenbach has suggested a three-fold increase, or do you think some other figure is more appropriate?

Dr. FECHTER. I wouldn't want to hazard a guess.

Mr. BOUCHER. You wouldn't want to hazard a—

Dr. DAUFFENBACH. Well, I think the important point to note is that getting a three-fold increase in the sample is not a three-fold increase in the cost.

Dr. FECHTER. In the cost, right.

See, and that's the point. And the other thing that—

Mr. BOUCHER. Did I misinterpret your remarks? I thought you had suggested a three-fold increase—

Dr. DAUFFENBACH. Three-fold increase—

Mr. BOUCHER.—in the funding—

Dr. DAUFFENBACH.—in the sample base.

Dr. FECHTER. No, in the sample—

Mr. BOUCHER. Oh, you were just saying the sample base?

Dr. DAUFFENBACH. Yes.

Dr. FECHTER. And that's the quality of the data here, you see? Now, I don't believe that anybody has really ever taken a very systematic look at how much money is being spent—how much resources are being devoted to the question of these projections analytic activities.

Mr. BOUCHER. Well, let me leave this issue because I think we have probably explored that as thoroughly as is useful.

Dr. FECHTER. Yes, sure.

Mr. BOUCHER. Should we be relying to some extent on private sector projections of future manpower shortages? And, I guess a corollary to that is, to what extent have you determined that the private sector makes these projections? Is there any evidence that there is some systematic means of making that determination outside government itself?

Mr. Ellis, would you care to comment?

Mr. ELLIS. Let me comment on some of the other comments, first.

I do have a very different point of view on some of this stuff. I'm bemused by what I'm hearing. Let me make a couple of heretical comments.

First off, it seems to me that the broad design of what NSF is attempting to do in the Scientific and Technical Personnel System is sound. You're going to need some kind of modeling mechanism to put together all the data, and you're probably going to need the particular components they call for. As far as how big the case base of data should be, it is my belief based on over 30 years of conducting applied research projects for this government that you can do responsive research in almost any level if it's done effectively and efficiently. And that's where I have my problems with what I see.

I don't think—I think actually the data base may not be that bad; and I don't think that the components that they have set in place, to set up the data, are all that bad; and I don't think the information itself is all that bad. The problem I have, principally, is in the quality of the analysis, the method, and accuracy, and depth, and frequency of dissemination, and the time it takes to get everything out.

What I am suggesting is that there is a tendency to try to cure problems with money. I would suggest to you that sometimes that backfires and all you do is take a bloated system and make it more bloated. I think it is incumbent upon the Congress to demand high performance, to demand work that sets leadership standards as science. I do not wish to be too harsh on my colleagues in the system. I know many of them personally, and I think they're a good bunch of folk. But I don't think we're getting good science, always, out of NSF or other parts of the Federal research establishment, and I think that's a disgrace. We ought to ask for better performance for the money we're spending.

As far as private projections, there is no private organization in this country with the resources to examine the broad occupational make-up of the United States. I suppose we could wave some magic wand and create some private organization like the Census that could look at the whole U.S. work force, but I don't see any possibility and practical way of doing that. This is clearly a Federal responsibility, and it seems to me that in many ways the Feds do a pretty good job. Particularly BLS does—given its mandate—an excellent job. The Census, I think, given its limitations does a good job. I think NSF has done a reasonably good job.

I think if I were in your shoes, I would think more of looking at what has happened as an initial step—all science takes time, all science stumbles some. And we ought to be thinking about building on the work that's been done to date, looking at it objectively, saying this is weak, let's refine that, and moving on rather than thinking of more drastic kinds of measures.

I would remind, finally, the committee that in my experience, the improvement of research systems is very much a kind of step-by-step, incremental process. And you don't go from nothing to a fully developed system overnight. The way you are going to get what you want is by forcing constant day-to-day improvement and attention to the details of these systems, and not by setting some kind of global expectations.

Mr. BOUCHER. I have a number of additional questions. I am just going to ask one and then defer to my colleague from California.

There have been some suggestions that the data that NSF collects and analyses is not made available on a timely basis, and as thoroughly as would be appropriate to the private sector and to others who are interested in receiving that data. To what extent do you think it is a significant problem, and what suggested remedies do you have for it? And who would like to comment on that?

Mr. BOUCHER. Let's see; let's begin with Dr. Dauffenbach.

Dr. DAUFFENBACH. I think NSF has done a fairly good job of dissemination of data. They have, for example, used the archives at the University of Wisconsin to make data sets available—the tapes themselves, the actual data from the postcensal survey, from the new entrants survey—and that was widely available to the research community.

I would be more chastising of the research community for insufficient interest in scientists and engineering manpower, which serves to my advantage to some extent, I guess. But it really surprises me how much attention in labor economics we pay to building another small model of labor market information flows and behavior of blue collar workers, and we're just not getting to the kind of level of detail that we need.

Mr. BOUCHER. Well, if I understand you correctly, the data is available. There are no problems with accessibility. There is a problem, perhaps, in people even wanting the data and asking for it.

Dr. DAUFFENBACH. There seems to be a problem of dealing—you are starting to see more articles on scientists and engineering labor markets—more concern, but there hasn't been the interest that I have, and I feel more of my colleagues should have.

Mr. BOUCHER. Mr. Ellis?

Mr. ELLIS. I had a call yesterday from somebody trying to prepare a statement for their CEO on questions like this. They've heard about shortages. They're curious as to what the availability is of computer scientists, physicists, and electrical engineers in southern California. I had to tell them, well, you can take a look at the 1980 Census. They weren't too happy to hear that, and they were even less happy to hear that there is going to be no data of that kind available for the 1990 Census, because Census isn't going to do occupational details at the level of states and SMSAs.

There is no information about people that is specific to their experience, to their particular specialties, and that is what users seek. It may not be what we look at in making broad, sweeping national policy assessments, but it's what the folks out there in the trenches of industry are looking for.

On the production side, it takes the existing system working through layers of contractors and all kinds of other complications, most of which is understandable for a Federal system. As we said in the prepared testimony, Federal systems are necessarily ponderous. They have wide audiences to deal with, but it takes this system, depending upon when you look at it, two to four years to come up with information on degree production in any level of detail.

I don't know where the Department of Education is at this very moment in getting out information on degrees in detail for say, women and minorities. I know a few years ago some of the information that DOE[1] had had to be scrapped because its contractors couldn't perform. That's not good enough. We have a clear instruction from industry people at EMC that they want to know about degree production within six months, and we get it to them that fast. That's the only kind of time frame that makes any sense to somebody who is doing human resource recruitment.

I don't see why the Feds couldn't be faster than they are—

Mr. BOUCHER. What about the NSF, is it fast enough?

Mr. ELLIS. Well, it's dependent upon the Department of Education's information for every kind of degree it looks at, other than Ph.D.'s. And it's all very nice to pay lots of attention to Ph.D.'s, but the fact of the matter is only six percent of engineers have doctorates. People with Ph.D.'s do not constitute the bulk of this work force.

You are, by the way, not talking about a small chunk of the American work force. Engineers alone are the biggest single professional group in this country outside of the combined numbers of elementary and secondary school teachers. You are talking about at least 1.5 million people in a hard-core count. You are talking about the parents of 12 percent of the college freshmen in the United States, by the way, and that's just the engineers.

I would side with a cynical remark made by Betty Vetter after one of these hearings years ago. I think many of you may know her, she's the executive director of the Commission on Professionals in Science and Technology, and Betty and I are cynics about this matter. We have the feeling that lots of people like to talk about it, but very few people want to see serious performance.

Again, I agree with my colleagues, we need to pay attention to money. It probably isn't enough. It is certain that many of the people laboring in the trenches would like to have better support, but at the same time if you are going to give more money, I think you have a right to insist on some serious performance.

Mr. BOUCHER. Would it help if the NSF had a requirement that its data be published on some kind of periodic schedule?

I'm sorry, let's—just one at a time.

Dr. Dauffenbach?

Dr. DAUFFENBACH. The—right here we have the "Science and Engineering Degrees 1966 to 1989". This is a publication that came out a couple of months ago,and given all of the 3400 institutions that we have of higher education across the country, or whatever that is, I think that that's pretty good for pulling degree information together.

Mr. BOUCHER. But there is no, as I understand it, periodic schedule upon which that kind of publication must—

Dr. DAUFFENBACH. There is no requirement maybe, but they certainly have an internal—

Mr. BOUCHER. The question is this, should there be such a schedule?

[1] Mr. Ellis indicates this reference is to the Department of Education.

Dr. Fechter?

Dr. FECHTER. Yes. I think the answer to your question is, it would help.

I'd like to also support though—having said that, I think it's true, you don't know when these things—you know roughly when they are going to come out, but you don't know exactly when they are going to come out. The only thing that's periodic is the *Science and Engineering Indicators,* which Congress mandates and comes out every two years. All right, so there is a message in that for you.

But I want to say also—I want to support Bob's comment earlier that to get this information out to users, you have to have a community out there to use it—who are interested in using it and you have to build that. I tried to make that point in my earlier remarks. We have to put money out there to researchers to give them an incentive to think about working with this information and working on these problems, but at the same time, I don't think the causality goes one way. It's not just because there aren't people out there that I think we have these problems.

And I think my colleagues at NSF would agree that the issue of dissemination of the information is important to address, that more effort has to be put into more effective dissemination—reducing the costs of people having access to this information. Right now the costs are very high, and there are ways that we can think about in which we can reduce those costs. Some of those ways are administrative, others may require legislation. There are privacy acts and confidentiality regulations that need to be examined in terms of whether or not they are reasonable with respect to providing access to researchers, for example, to these data files. And I think those are issues that do need to be addressed.

Mr. BOUCHER. Thank you, Dr. Ellis.

Would you like to comment, Dr. Dauffenbach.

Dr. DAUFFENBACH. I'd like to make one other point and that is—in terms of larger thinking, and that is, I don't think—I think the problem with—in contrast to Mr. Ellis—I think the problem with our data systems is that we haven't given it enough thought about how we might do things better, and we've approached it too incrementally and just compounded on our errors.

And I believe that, for example, with respect to the college-educated population, that we would do much better as a nation if we got agencies together and funded a large scale survey, postcensal survey, related to the college education population, and that way a lot of different areas—the educationalists could get data they need, the health science people could get data they needed on college-educated personnel, and the science and engineering community could get the data they need—and that way we could really economize.

Mr. BOUCHER. All right, thank you.

I'm going to defer to my colleague from California.

Mr. PACKARD. Thank you, Mr. Chairman.

I had several questions on the data gathering systems, and so forth, and I won't dwell on those to any length because I think we've spent time on that. I would be interested though in very quick answers, perhaps, on the gathering system—how elaborate it

ought to be. Are current gathering systems adequate, or do we need additional more elaborate gathering systems of data? And how often should the data be updated in order to make it effective in interims of forecasting?

Sir?

Dr. FECHTER. I'd like to say that I think the recommendations made by the NRC committee on this particular data system were correct in terms of—ought to be followed. I think that would be very helpful in moving us in the direction of getting better information for projections for supply and demand.

I think, though, the question of how often we do this, the answer to that question depends very much on what issue it is you are trying to address. I like to say to people, if you don't know where you are going, any road will take you there. You have to know where you are going with this information, and I think that the timeliness issue depends on the problem.

And I'll give you the extreme examples, okay. We need to have information on the distribution of the population in this country so that we can do the right thing with respect to how we allocate electoral districts in the United States. Now we don't have to do that more often than every 10 years because that may be enough to take into account the problem. At the other extreme we believe and we have in fact set policy so that we have an unemployment rate number every month.

And the answer to the question how often you do something, it depends how rapidly things change over time. Unemployment rates, market conditions in the aggregate economy change very rapidly. And so you need that information very quickly to make policy. On the other hand, science and engineering labor markets, while affected by the business cycle to some extent, don't move that rapidly. The changes year by year, for example, or certainly month by month, are not dramatic changes. And so timeliness that says every couple of years in terms of frequency may not be a bad approach, and that's about the way it works now.

Mr. PACKARD. Thank you.

My primary thrust in my questions will be more to what do we do even if we had accurate data, and if we—our systems were working to provide the information that we need to do appropriate forecasting and appropriate counseling and make a change in the work force. If there are shortages or excesses, how do we best use that data to bring about the changes that are desired and needed? And I would like to ask what do we now do with the data, how is it used? And I would be interested in your evaluation of our counseling and aptitude testing systems in our schools as it relates to trying to solve some of the problems that our data would indicate.

Maybe Dr. Dauffenbach?

Dr. DAUFFENBACH. I think that our data systems are used in—there's a lot of them. There is an infinite demand for data. It's a bottomless pit; you have to make choices.

I think that NSF has done a very good job in looking at the content of the postcensal data system. They've done a very good job of redesigning the questionnaires that relate to the new entrants survey, looking at people right after they get out of college and as they enter the labor market. There is a lot of very important infor-

mation that we need to generate there. But just to the extent—the kinds of questions that you are asking, how can we use them for counseling and advising purposes? There is a lot that we don't know about people's careers in science and engineering and a lot we could be learning from the data system on that. But the problem is, the more complex that the instrument becomes, the more problems you have in getting people to fill it out and respond. Your response rates go down. So you've got a lot of choices you have to make.

The primary aim of the postcensal survey is to get labor market information, to get education information, earnings and things like that related to employment, and some handicapped information, even, is taken on it. So you have to focus in questionnaire designs. What I think we need to do and think more about doing is having special questionnaires, have this sample base—enlarging the sample base and making use of that sample base for special issues, like having a set of questionnaires that relate particularly to why somebody chose a career in science and engineering and how satisfied they are with that career, so you don't over burden the respondent each time you as a survey. There are a lot of trade-offs that have to be made.

Mr. PACKARD. My concern is that we have been trying to—or through our data collection systems we determine that there are shortages in this field or that field, or perhaps surpluses in another field, and we tend to try to direct young people and push them into directions that they either are not—don't have an aptitude for, or an interest in, or at least a yearning desire in. I am persuaded that career success is far more likely when people go into a field that they have dreamed about doing all their life, that they would just love to do rather than being directed by numbers, by data, by shortages, by salaries, by other reasons.

I think statistics show that success, even the natural success, far exceeds those that go into a field for other reasons other than for a great love of the field they're in. And we often make a great mistake by directing people, even with the data and sometimes even because of the data, we direct people into areas that they are not suited for or interested—or at least burning—have a burning desire to get into. And that's, perhaps, where I am interested in—how we use the data and how effectively it evaluates that aspect of our students and our entry-level people—into the areas of what are their desires, what are they good at, what would they be successful at.

And then another question that perhaps will be—and then maybe you will want to respond to the first, Dr. Fechter, is the question of whether the market place manages the salary or the money aspect to create a natural draw into a field and thus accomplish the same goal as a multitude of data collection systems.

Dr. FECHTER. Yes, okay—

Mr. PACKARD. And then I'd be interested in Mr. Ellis, too.

Dr. FECHTER. I resonate to two parts. As a father of four, I resonate to your concerns about how these decisions get made. I would respond to that by saying that what I think these information collection systems and these forecasting models can do is provide important information about job opportunities. That's something people should know. My Chicago training says that information is

a lubricant of markets, that information on which people make decisions—they should have adequate information so they can make intelligent decisions. That's what's necessary. Job opportunities is part of that. But these models can't tell us things that are also important, as you correctly suggest.

One of these things is, what are these people doing? Okay. What kinds of aptitudes do you need for that kind of job opportunity, and so on. The Bureau of Labor Statistics comes closest to providing that kind of information now through its "Occupational Outlook Handbook". In there, they talk about how fast they expect certain occupations to grow. They give information about the kinds of training you have to take to get into those occupations. That's useful information.

The next question is, given that information from a place like that, how does it get to the kids—the most important part of this decision making process. And I'm afraid, there my own experience tells me the counseling end of things is woefully weak—that we don't have a good system whereby this information gets from the government agencies that produce it to the students who need to use it. What usually happens is, when the students are bright enough and quick enough, that they know where to go look for it. But there are many people out there who need the same kind of information, and somehow or other it doesn't get to them.

Mr. PACKARD. If that's true, then Mr. Ellis's point—that is that throwing more money at it is not necessarily going—the production of greater, more accurate, and better data, then if it doesn't get to where it becomes useful, is a significant—

Dr. FECHTER. It's—

Mr. PACKARD.—stumbling block that needs to be—

Dr. FECHTER. Yes, absolutely—

Mr. PACKARD.—also studied to see, then—

Dr. FECHTER. I agree—

Mr. PACKARD.—how we transfer the data—accurate or inaccurate as it may be—how we transfer that to those that can really make the change. The whole purpose of gathering information is to bring about a change in a circumstance—social circumstance—that needs to be corrected.

Dr. FECHTER. Right.

Mr. PACKARD. Shortages of engineers, shortages of scientists and—or whatever. And if that—if there is a link that is simply not in existence or is poorly linked, then we waste money at one end—

Dr. FECHTER. Right.

Mr. PACKARD.—and the weakness at the other.

Dr. FECHTER. It's a systems problem. I think you are right to say that.

Mr. PACKARD. I'd be interested in your comments, Mr. Ellis.

Mr. ELLIS. Well, I agree with your perspective with respect to what ought to be available to young people and the factors that ought to count in career choices. One off-setting bright aspect of this is that going into scientific careers is not entirely a matter of whim. It takes a certain amount of skill. It takes a certain amount of hard work. And I don't think there is infinite elasticity of the ability of people to decide to do this or not do it. I also think to some extent many people who chose these careers probably know

very early on, while they are still in grade school, perhaps in some cases, that this is what they want to do.

I get calls constantly from people who wish to provide counsel or advice to children, often for money—guidance people, journalists, writers of one sort or another—and I must say I'm appalled by the dependence of these people on things like how much—what the salaries are, for example. There is an assumption that, if the salaries go up a little bit, this is going to make a great big difference in kids' career choices, and as a purveyor of salary data and somebody who collects a great deal of it, I simply do not believe it. I think that there is a need—a very major need to improve the quality and nature of materials that go to youngsters in schools about these professions.

There is a fascinating column in the *Washington Post* just a few days ago about the influence of engineers on society and the typical roles they can play. This kind of material is the sort of thing that needs to be put in the hands of kids, and this has been a major concern of the engineering societies for some time. I think that support for dissemination of the kinds of stuff that comes out of these data systems would—well, I remind you of what Joe Wholey used to say about the design of all Federal research systems. And that is, they should be aimed at specific decisions and products, and that if you can't set up these systems with an eye—before you ever give them—put one dime into them—of what decision they are going to affect or what product they are going to culminate in, why spend any money on them in the first place?

As far as some of the other comments that have been made that hook into this, as Alan has observed, I think two year cycles, which are the ones that NSF has been using, are probably adequate. The problems where we have—the places where we have problems with these data are not so much in the cycle duration, they are more matters of dependency on what, to me, strikes me as terribly old-fashioned and long past the need for complete revision—procedures of classification and treatment of the characteristics of these folks.

Let me give you a simple example. Most technical workers have multiple specialties and skills, particularly as they get more experienced. And yet we continue to insist that people we track in these systems be labeled as a whatever, a computer scientist, a physicist, a mathematician, when people may have experience in all three. And I want to tell you, when you count people this way, this means you seriously underenumerate the specialists who are out there because many people can do more than one thing.

One of the things we need to do is start counting multiple specialties. That's not done any place. There is—one of the things we need to do is to find ways to cut down the terrible lag of 20, 30 years that it takes for emergent specialties to get to the point where bean counters can count them. A major interest of industry and of policy makers through this country, Robert Mossbacher of Commerce—the New Technology Report from that agency—and that was one place where it comes to mind. There is a great deal of focus there on the profession of manufacturing engineering, and yet to this day, very few universities label students as manufacturing engineers.

The only measures we really have of resources in this area come from the membership records of the Society of Manufacturing Engineers out in Detroit. It's going to take 15-20 years before we have a handle on these people. I think that's something we ought to try to do something about. So when we are talking about time lags, I'm not thinking of the two year cycle. I'm thinking in some cases of the 20 to 30-year lag we have before we begin to catch up with information about what's happening right now.

One other point—

Mr. PACKARD. There is another point on that, Mr. Ellis. Even when we see that coming, we don't really start to do anything about it until the shortage is already there or the change is already made. We've seen it in the medical profession, we've seen it in teaching, we've seen it in a variety of fields where we don't respond to the information until we have almost hit bottom, and then it's time to do something and it becomes a crisis.

Mr. ELLIS. Yes, well, I make a living designing systems to do this sort of thing. And as somebody who does that, I simply do not see that they necessarily have to be this inefficient.

I would make one simple suggestion—and there is more detail about it in our prepared statements. We're talking here, pretty much exclusively, about the lead system for providing this data in the United States. That is NSF. I would simply point out that's not the only step available to learn something about scientists and engineers. There are other things that could be done that would complement what NSF does and perhaps provide different kinds of perspectives and different kinds of—particularly levels of detail—and this is a society that values the effects of competition and more than one option in dealing with any problem.

I think one of the things that you ought to consider is alternative approaches to dealing with some of these same issues, like the one—the one in particular that we've mentioned is the notion of reopening NORC's[2] major data base of the U.S. college graduating class of 1961. Here is a huge data base on people who are now at the peaks of their careers. If we go back to those folks—and NORC says they can do it—we can learn a lot about the career histories of the people who are, at the moment, running the science and engineering establishment in this country. I think that would be a very valuable exercise, and it's a bargain because the project is already set up. Things like that have great appeal for me because they're moves that are tangible, specific, and a good deal for the money. I think you ought to consider them.

Mr. PACKARD. Thank you very much, Mr. Chairman, that's all I have.

Mr. BOUCHER. The gentleman from Maryland, Mr. Gilchrest.

Mr. GILCHREST. Gentlemen, I'm, just wondering—I question, I suppose, the specific disagreement about how we gather and disseminate the information, and I'm going to ask a few things but basically it's going to be how you three have collaborated in the past—your different organizations. Is it useful to get together to find out specifically what differences there are and, maybe, it is

[2]Mr. Ellis indicated that NORC is the National Opinion Research Center at the University of Chicago.

possible to get a three page report on the specific differences of the different perspectives on this problem?

Dr. Fechter, you've said that in this effort—and you quoted somebody that said it's a hardy perennial and we need to pay closer attention to this on a more consistent basis, and if you do pay closer attention to it on a more consistent basis, then the whole process will improve a little bit.

And, Mr. Ellis, you said that basically the process is good and it's sound, but from my opinion—I wrote down "taskmaster"—we need to whip people up to shape to perform at their peak and we don't need to pour any more money into it, but the system is basically, fundamentally sound. And then, Mr. Ellis, you made a comment about the economic analysis of New York University that could become a part of this system. So I wonder if you could just make some—I guess I have to go vote here pretty soon. Is that—

Mr. BOUCHER. The Chair would advise the gentleman—

Mr. GILCHREST.—a plausible question?

Mr. BOUCHER.—that we have about five minutes, and so if you want to—

Mr. GILCHREST. Okay. Is that a plausible question, and are there certain areas that can be prioritized so that we can get a sense of the differences between—

Dr. FECHTER. I'll take a stab at it.

My impression is that we interact a lot. I think it's fair to say that, when the Engineering Manpower Commission has it's session on supply and demand, I'm going to be there. I go to their meetings; they come to our meetings. Bob, when he gets east, we try to get together and we talk. It's hard to reach him in Oklahoma because of the static in the oil fields, but we try to get together and talk to each other often. My sense is—the question is a good one. The question is, given all these things that you have to do—you've got to make the data base better, you've got to do a better job of analysis, you've got to do a better job of dissemination—and given limited budgets, which should be done first.

How do you allocate those resources in a way that will give us the best possible yield for the bucks we're going to spend for this, okay? And I don't—I will candidly say that we haven't really done a good job, I think, yet in terms of trying to set up such priorities, and I think it is a very appropriate question to raise. I'm not sure we can get together and give you the three pages you asked for, but clearly that's a relevant question that needs to be addressed.

Dr. DAUFFENBACH. I think that since that committee—looking at that document, you will note that a great deal of time was spent on the postcensal survey, that is the survey that launches you into a new decade of gathering information longitudinally on a group of individuals. And I think that is probably the key data base. Others I would say: data base on doctorate recipients; survey of doctorate recipients; files survey of requirements for doctorates—that is handled in Alan's house; that is a very key data set. And I think the CNSTAT Committee spent the time on the most important data sets regarding the people's actual experiences out in the labor market. What they've earned; what they're doing.

I'd like to just make one other comment related to your comment, Mr. Packard, because I think it was right on track: Why we

need these data to look at our social problems; how to correct our social problems. And that to me is a principal problem with our sample size base, women and minorities—how they might become more involved in science and engineering careers, knowing more about the career bases, what they've done, how well they're doing in their jobs, how well they like jobs in science and engineering. These are things that need to be conveyed, but we just simply don't have the sample base in our current designs to convey that kind of information.

Mr. ELLIS. I would like to comment.

It's very difficult to come up with cogent, short summaries of what ought to be done. I agree if somebody ought to do it, it seems to me that there—one thing that could be done and isn't being done, at least not enough as far as I can tell—there are a bunch of different efforts underway that bear on these matters at NSF, just within the one agency. One does get the impression that the people at Policy Research and Analysis, Science Resource Studies, and the Division of Engineering Infrastructure all probably need to speak to each other more often and make better use of each other's efforts.

The work on input/output modeling done up at N.Y.U. was sponsored by Engineering Infrastructure. It doesn't seem to have been fed into the stuff that was done at SRS, which was using similar methods and coming up with conclusions that no one can believe. Something is happening to the data between the time that it goes into the model that SRS runs and the time that it comes out. I mean there is no other way to account for the fact that they are coming up with information that says that the population of engineers increased by three times the number of degrees in two years flat. I don't want—people simply do not believe that.

This does NSF no good. So there should be more coordination within the agency and also within the establishment on a wider level that deals with this government-wide. That is the Bureau of Labor Statistics, the Census, and other people. There probably isn't enough coordination.

As far as feeling that the system is sound, it's very difficult to have any one word applied to the system. Parts of it are sound. Parts of it probably need attention. I can't do better than that in a short response.

Mr. BOUCHER. Unfortunately, that short response will have to be it for the moment. We have about 10 minutes remaining now to answer a call to the House. I will ask this panel if they will stay in place for the time it takes us to vote and return. Mr. Browder does have some questions to propound, and I have a couple of follow-up questions, as well.

The subcommittee stands in recess for approximately 10 minutes.

[after recess]

Mr. BOUCHER. The subcommittee will come to order.

Mr. Browder has not returned. He did, however, leave with the Chair a question that he would like to have propounded to this panel, and the Chair will ask that question for him.

There obviously will be less defense spending over time. And as we scale back expenditures for the Department of Defense, that may well have some effect on the base of scientists, and/or engi-

neers, who are employed in the Defense Department directly or contractors who are doing defense-related work. And the question is this, to what extent is that probability reflected in the models that the government is presently putting forth and, if not, what should be done now in order to properly take that into account?

Dr. Fechter?

Dr. FECHTER. The answer is—the short answer is, yes, I think it is taken into effect. All of the input/output models that were referred to here have government sectors. Now, some of them are more detailed in terms of defense sector, and particularly the one that NSF uses is based on a model that breaks out 50 line items as a defense budget and talks about the implications—could talk about the implications of each of those line items on manpower requirements. So, in that sense there is that work.

Some people have—I've done a little work on engineers looking at the question of what's the impact of the GNP, real GNP, and the share that GNP that goes to Defense on engineering employment. And there is a significant—of course, GNP has an effect—when the economy goes up the employment of engineers goes up, but the share of the budget going to defense has a significant impact too. Defense is really a very heavy user of engineering talent, and you find that, as the share of the GNP going to Defense goes down, you are going to find engineering employment going down slightly, as well. These models can address that.

They haven't—we did a study when I was at NSF, way back when, in my youth—we commissioned a study to look at the impact of the defense build-up on science and engineering manpower, and that's where that capability comes from. And that time they found that there wouldn't have been—at least through the period 1987 to—1982 to 1987—it wasn't going to be any problem. And indeed, if you look at the history of this decade of the 1980s, the Defense budget did not seem to be a serious problem causing perturbations in science and labor engineering labor markets.

Mr. BOUCHER. Okay.

I have one additional question. And I realize we could probably spend hours talking about this, but let's don't. Let's try to keep the answer as succinct as you can.

I think the fundamental issue for us as policymakers in this area is getting a clear sense from you as to what kinds of data the Government ought to be collecting that it's not today. I mean there is a general belief, I think, that our models are insufficient. Give us in a very precise summary, if you would and very succinctly, the kinds of data that we ought to be getting that we are either not getting today or getting inaccurately today.

And, Dr. Fechter, could we—I'll start with you.

Dr. FECHTER. Let me start. I'm going to simplify your question by assuming that we are dealing with particularly NSF in terms of the stuff—

Mr. BOUCHER. That's correct. We are.

Dr. FECHTER. Okay. There I'd say a number of things. One is I think that the standard measures of labor market conditions really don't apply very well in these markets, unemployment rates, for example. One doesn't have a sense from unemployment rates about what's going on in these markets because they tend to be very low,

and they don't really vary a great deal. There's a lot of noise in the data because of sampling errors, and so on, as mentioned before. So I think we need to think carefully about indicators of market conditions and do a better job of understanding what those indicators are. That's, I think, an important one.

I think there's—the other one that came to me when you asked the question has escaped my mind, so I will demur at this time and allow others to answer the question. I just forgot what—

Mr. BOUCHER. All right. Dr. Dauffenbach?

Dr. DAUFFENBACH. I think that we need a lot more data on women and minorities. As I've stated, I think our problems are basically in terms of sample size. I think we have the right frames to get our data, but we have a lot more foreign participation in our work force as we go through time. About half of the Ph.D.'s are foreign nationals who earn Ph.D.'s in the United States and, as nearly as we can tell, are staying for considerable times to participate in the U.S. labor force, to some extent.

And there are studies going on now to figure out—give us more information on that, so we definitely need more information on foreign participation—internationalization of our work force.

Mr. BOUCHER. All right. Mr. Ellis?

Mr. ELLIS. One thing that immediately comes to mind is the ability to make distinctions by levels of experience or age is not just a policy matter, but is a practical political proposition. The things that cause heat—and there's a great deal of heat in the engineering community over claims of shortages and surpluses—often are related to fears of experienced engineers about age discrimination and the sense that people have that you can be milked dry and turned out on the scrap heap, which is the way people talk about these things.

So one thing that we cannot do with the existing data, and which the community senses and hollers a lot about, is the difference between demand and supply for young graduates and demand and supply for experienced people. That, again, is something we don't deal with with the existing data, but which we could if we paid more attention to the tracking of the experience level of people in the work force.

Dr. FECHTER. I remember.

Mr. BOUCHER. Yes, Dr. Fechter?

Dr. FECHTER. I remember three. Okay, and I'll be brief.

One is the perennial quality question. We may know the number of bodies in this work force, but we don't know a great deal about how to assess their performance as workers. I'm reminded of that by the article I read in this morning's paper about the Hubble Telescope, which is up there turning around with a flawed lens. And now there are about two or three other flaws that need to be dealt with in that telescope, as well, which may require a trip to fix it. And the question is, what's going on there in terms of performance that lets this happen?

So quality is an important one, and like beauty, it lies in the eyes of the beholder. And it's very difficult to assess, but we need to look at it.

The second one, I think, is the pipeline—getting a better sense of flows into and out of the educational pipeline, particularly flows

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out. We lose a lot of people in science and engineering careers because they don't stay with it. I think we have to know more quantitatively about how many did we lose that way, and more qualitatively about why. That's important.

And finally, but not least—in my testimony, as a matter of fact, I suggest this—and that is we need to know more about population by degree level and field. We don't know how many people in the United States exist now who are baccalaureates—who have baccalaureates in engineering, for example. That's not a number that's easily derivable from the existing data systems. The CNSTAT report on the STPDS, the data system for NSF, has made recommendations, which would move us much better in that direction, and I would strongly urge that they be supported, and we move along those.

Mr. BOUCHER. Thank you. Thank you very much for the succinctness of that answer. That was very informative. Thank you.

Mr. Fawell, do you have questions of this panel?

Mr. FAWELL. No, I haven't.

Mr. BOUCHER. Anything else, Mr. Packard?

Mr. PACKARD. I don't. I was interested, of course, in the foreign component, which we had not discussed much, but I think Dr. Dauffenbach related to that.

Mr. BOUCHER. The Chair thanks this panel for its attendance this morning and its helpful testimony.

And with that I would dismiss this panel, and welcome the second, comprised of Dr. Kenneth Brown, the Director of the Division of Science Resource Studies for the National Science Foundation; and Dr. Judith S. Liebman, the Chairman of the NSF Advisory Committee, Divisions of Policy Research and Analysis and of Science Resource Studies. Without objection your prepared statements will be made a part of the record, and the subcommittee would welcome a five minute oral summary of your prepared statements, leaving ample time for questions.

And, Dr. Brown, we will be pleased to begin with you.

STATEMENT OF KENNETH BROWN, DIRECTOR, DIVISION OF SCIENCE RESOURCE STUDIES, NATIONAL SCIENCE FOUNDATION, WASHINGTON, D.C.

Dr. BROWN. Thank you, Mr. Chairman, and members of the subcommittee. I appreciate this opportunity to appear before you this morning to discuss the issues raised in your letter to Dr. Massey. As Director of the Science Resource Studies Division, for only just a few weeks now, I've spent, still, a considerable part of my time during these weeks learning about this program because it's one of our most important ones. It is—personnel is just one of our subject areas, I should remind you. We also collect data on science and engineering activities, R&D spending, and the education of scientists and engineers. We also help produce the National Science Board's Biennial *Science and Engineering Indicators.*

Getting back to the personnel program, your main questions had to do with the so-called CNSTAT Report. This was the committee of the National Academy of Sciences, which back in—I believe it began its work in about 1986 or 1987, and it made its final report

in 1989—this was quite a large document, a big 300 page report with many, many specific criticisms and comments. By and large, CNSTAT supported our mission, and we thought it was a good report. We've—as a whole, NSF has endorsed the basic thrust of the report, many of the specific points, and currently we are working to correct the problems identified. And we've already made quite a bit of progress, in my view.

Now in response to your questions about exactly what we have done, I have provided you with a detailed list, which shows the CNSTAT recommendations, and, then right next to them, exactly what we've done in these regards. So I'll only summarize those points, which get very technical very quickly.

First of all, the CNSTAT Report criticized our NSF definitions of scientists and engineers. They said it led to confusion and ambiguity, and I think they were right. So as recommended, we will now use two definitions, discarding our old way of looking at it. But the two definitions—one based on respondent's field of education and the other based on their occupation.

The second thing we are doing—and have done, really—is to improve our data collection techniques in order to increase the response rates in our surveys. That's crucial to doing things efficiently.

Third, we're refining the statistical designs of our survey to give more information on the sub-groups of interest such as women and minorities, without hurting the overall efficiency of the design. This, too, will give us more information per dollar spent on the surveys.

And finally, we are trying to increase the statistical expertise that we have to work on these problems, not only in our staff, but also in the outside experts we draw upon—outside panels, such as CNSTAT itself, consultants and contractors.

Mr. Chairman, I want to emphasize we are well beyond the point of just reviewing these recommendations. We're taking concrete action to implement the needed improvements.

There were a number of questions in the first panel about priorities, about how do you do these things, what are your priorities? Let me try to give a quick answer to that.

This morning we've talked about three basic activities: one is the surveys that is going out, asking people who are—you know, what do you do for a living and what's your education; the second part is sample design; and the third part is modeling. Now, of these three activities, the surveys are very expensive. Just as a ball park figure, it might cost $50 for every person in your sample. Say you want to increase your sample size by 20,000 people. Then you have just spent another $1 million. Going to big increases in our sample size would be very, very expensive.

Sample design, however, and modeling, while not cheap by any means, are a lot less expensive because they basically involve brain power, smart people sitting down with computers. So what are our priorities? We try—our priority is sample design. That is using the money intelligently. Revising our samples—our surveys according to the CNSTAT Reports to get more results out of the money.

Number two priority, I would still have to say is the survey in the sampling. Even though it's very expensive, we still try to allocate as much money as we can to get large samples.

Modeling comes number three. We feel if you don't have good data, you can't—there's no point in modeling. And I will tell you that in SRS a very small portion of our budget, well under 1 percent, is actually spent on modeling.

Well, that brings me to your other area of concern. And that is the estimates of future demand for scientists and engineers. We produce some of the data you would need for that kind of analysis, but not all of it. For example, a complete analysis of the future market for scientists and engineers would also require—besides our data—sources on the economic environment, industrial growth, defense spending, technology, wage rates, and so forth.

There was some attention in the early panel to the numbers coming out of NSF some years ago about shortfalls in engineers and scientists, and I just want to remind you SRS was not the source of that particular set of numbers. We just don't do much kind of modeling. And, indeed, that wasn't—that was a very—that was a study that was done a couple of years ago somewhere else in the Foundation. But we do agree this is a vital topic, the outlook in modeling for engineers. And mainly we look to the research community for work on it. As Professor Dauffenbach indicated in his testimony, SRS has funded small amounts of money for modeling supply and demand for engineers.

I want to let you know, however, that another part of NSF, the Directorate for Biological, Behavioral, and Social Sciences—that is the part that is much more involved in grant making than we are—does have a new initiative aimed at improving the methods for estimating the supply and demand of engineers and scientists. They have had their competition for research grants, and it is likely that a number of awards will be made within the next month or so.

Finally, Mr. Chairman, let me mention a matter that was not raised in your testimony—in your letter to Dr. Massey. SRS has recently found itself in the unaccustomed position of being the subject of press coverage on its management operations contracts. We at NSF are committed to establishing SRS as a first rate Federal statistical agency. This is our goal. We are committed to our responsibility to be an independent, authoritative source of accurate and useful data on science and engineering. This is also the objective of our work on the personnel data system discussed today. And it applies equally to the numerous other data collection programs in SRS who are management operations contracting and personnel practices, that serve as the foundation of our work.

Mr. Chairman and members of the committee, thank you for your interest in these matters. This concludes my statement. And as I indicated, I have provided a very detailed statement of how we're dealing with the recommendations of the Committee on National Statistics. Thank you.

[The prepared statement, plus attachment of Mr. Kenneth Brown follows.]

Statement of Kenneth M. Brown

Director, Science Resource Studies

National Science Foundation

July 31, 1991

Before the Subcommittee on Science

of the

Committee on Science, Space, and Technology

U.S. House of Representatives

Mr. Chairman and members of the Subcommittee, I appreciate this opportunity to appear before you to discuss the issues you raised in your July 11 letter to Dr. Massey pertaining to our Scientific and Engineering Personnel Program. As the director of the Science Resources Studies Division (SRS) only since July 8, I have spent a considerable part of my time since then learning about this program.

This operation is only one of the division's programs. We also collect data on science and engineering activities, research and development spending, and education of engineers and scientists. We also support the development of the National Science Board's biennial Science and Engineering Indicators.

The National Science Foundation has had the responsibility to collect data on science and engineering personnel for almost four decades. The present system--the Scientific and Technical Personnel Data System (STPDS)--is a survey-based operation that was designed in the 1970s.

In 1986, NSF commissioned the Committee on National Statistics of the National Academy of Sciences to evaluate the STPDS. The Committee (commonly referred to as CNSTAT) convened a panel of experts, which issued its final report in 1989--a document of more than 300 pages with numerous recommendations on

many aspects of the STPDS. The report was supportive of our mission, but pointed out several critical improvements that needed to be made. NSF has endorsed the basic thrust of its recommendations as well as most of the specific points. Currently we are working to correct the problems identified in the report, and already have made substantial progress in meeting many of the CNSTAT Committee's recommendations.

In response to your questions about planned and completed actions to improve NSF's data system, we have attached to this statement a detailed listing of the NRC recommendations and the NSF response and progress to date on each of them.

The main features of our plan are as follows:

1. The CNSTAT Committee report criticized the definitions NSF used for scientists and engineers, arguing that these definitions created ambiguity, noncomparability with other data, and a bias in estimates of growth in the number of personnel. As recommended, the STPDS of the 1990s will use two definitions of scientists and engineers--one based on the respondent's educational field and another based on the occupational field.

2. We have taken steps to improve our data collection techniques in order to increase the response rates for our surveys. This is critical to ensure that we receive enough responses to give us

confidence in the results.

3. We are refining the statistical designs of our surveys to better meet the need for information about subgroups of interest to our users without unduly sacrificing the overall efficiency of the sample design. This will enable us to get more information per dollar spent on the surveys.

4. We are steadily increasing the statistical expertise that is brought to bear on our projects. Indeed, the CNSTAT report itself was an NSF initiative. We are upgrading the statistical know-how of SRS staff through recruiting and training, and we use outside panels, consultants, and contractors to examine our work and to improve our plans.

I want to emphasize that we are well beyond the stage of merely reviewing the recommendations. We are taking concrete action to implement needed improvements.

Another area in which you have expressed concern pertains to NSF activities designed to improve the estimates of future demand for scientists and engineers.

SRS produces only some of the data which would be necessary for such analyses. For example, a complete analysis of the future market for scientists and engineers would require not just

our information on science and engineering personnel, but also data from other sources on the economic environment, including industrial growth, defense spending, wage rates, and so forth.

We do agree that this is a vital topic, and we look to the research community for work on it. Indeed, the Foundation's Directorate for Biological, Behavioral, and Social Sciences has recently undertaken an initiative aimed at improving the methods of estimating the supply and demand for scientists and engineers. A competition for research grants was held, and it is likely that several awards will be made within then next month or so.

Some of the questions that such research might deal with include:

- How do expected career earnings determine decisions to enter science and engineering fields?
- What is the effect on the market for scientists and engineers of economy-wide research and development spending, technological change, defense spending, and the level of economic activity?
- What kinds of data are needed to produce such analyses?
- How do labor market conditions affect enrollments in science and engineering fields?
- How do financing arrangements for education affect career choices for women and minorities?

Finally, let me mention a matter that was not raised in your letter to Dr. Massey. SRS has recently found itself in the unaccustomed position of being the subject of press converage on its management, operations, and contracts.

We in NSF are committed to establishing SRS as a first rate statistical agency of the Federal government. We are also committed to our responsibility for serving as an independent and authoritative source of accurate and useful data on science and engineering.

This is the thrust of our work on the Personnel Data System discussed today, and it applies equally to the numerous other data collection programs in SRS, and the management, operations, contracting, and personnel practices that serve as the foundation of this work.

Thank you for your interest in these matters. This concludes my statement. As I indicated, a detailed statement of how we are dealing with the recommendations of the Committee on National Statistics is attached.

Attachment to the Testimony of Kenneth M. Brown

Before the Science Subcommittee

of the

Committee on Science, Space, and Technology,

U.S. House of Representatives

July 31, 1991

Prepared in the

Personnel Program

Division of Science Resources Studies

National Science Foundation

STATUS OF THE PLANS FOR THE SCIENTIFIC AND TECHNICAL PERSONNEL DATA SYSTEM FOR THE NINETIES

July 31, 1991

Objectives of the SRS Personnel Data System

The basic purpose of the Scientific and Technical Personnel Data System (STPDS) is to:

- Provide data on the number and characteristics of scientists and engineers in the United States.

- Measure the supply of individuals with the skills needed for employment within the various S&E fields.

- Determine the impact of demographic characteristics (such as sex, racial/ethnic characteristics and disability) and type of education on such "outcome" measures as labor force participation, employment status, field of employment, and salary.

The STPDS is also a valuable source of information on the "flow" of individuals with S&E degrees among occupations over time. In the Postcensal Survey we are also able to obtain information about the number and characteristics of individuals who are employed in S&E fields but do not have S&E degrees.

Overview of NSF's Implementation of the CNSTAT Recommendations

Since the CNSTAT report was issued, SRS staff have expended considerable time and effort on planning the successful implementation of needed changes. They have been assisted by consulting services provided by Mathematica Policy Research and by technical working groups of experts in relevant technical and content areas. These activities have included:

- Redesign of the questionnaires to be used to: obtain richer information about the S&E population; increase comparability among NSF's surveys and between the STPDS surveys and those conducted by other federal agencies; increase response rates; and decrease response bias.

- Evaluation of alternative sample designs for the surveys. This process should enable us to allocate our sample to meet our information needs in a more cost-

effective fashion than was true in some of the 1980s surveys.

- o Improved data collection methodologies designed to provide more reliable data than were obtained in the 1980s.

We believe that we have made significant progress towards implementing the recommendations for improvements made in the STPDS. We fully expect that the 1990s STPDS will avoid the problems which beset the 1980s surveys.

Current Status of NSF's Implementation of the Specific CNSTAT Recommendations

Recommendation 5.1. The National Science Foundation should continue to be the lead agency within the Federal Government for providing comprehensive data on the science and engineering personnel resources of the nation. NSF must undertake to provide the budget and staff resources and institutional support necessary to develop and maintain a personnel data system that will adequately meet the needs of the 1990s and beyond.

STATUS: We agree that NSF should continue to be the lead agency. NSF is the major federal agency with specific responsibilities to provide information and analyses related to all science and engineering personnel. Also, among all federal agencies, only NSF has a broad interest in both the education and utilization of scientists and engineers.

In order to ensure that the 1990s STPDS will meet the nation's needs for manpower data, NSF has made a ten year commitment to fund the STPDS at a significantly higher level than in the 1980s. NSF's commitment to the system has also been reflected in the hiring of new staff for the STPDS planning group who have had experience at BLS, Census, and HHS and expertise in research methods and statistics. Further, we have used highly qualified consultants and review panels to assist us in our redesign efforts and we hope to have an American Statistical Association fellow with SRS next year.

Recommendation 5.2. Other federal agencies will continue to collect data in support of their own missions that pertain to science and engineering personnel. In order to enhance data comparability and utility to the extent practicable and to reduce duplication of effort and costs, NSF should play the lead role in coordinating federal data programs on scientists and engineers. Within the framework of established federal classification

schemes, NSF should encourage standardization of key questionnaire items and classification variables for science and engineering personnel across agencies.

> **<u>STATUS:</u>** **With the assistance of staff at Mathematica Policy Research (MPR), the contractor selected to assist us with redesign tasks, we have reviewed previous STPDS questionnaires, relevant data collection instruments used by other Federal agencies, and OMB guidelines in order to select questions to constitute the core instrument for the STPDS in the 1990s. We have sought to make the questions in our draft Postcensal Questionnaire as directly comparable with those used elsewhere as feasible in light of our objectives for the STPDS.**
>
> **When the questions used to measure S&E concepts by other agencies did not meet our needs (e.g., if they were not sufficiently detailed), we explored ways to collect the information we need, while maintaining the ability to make comparisons with other data bases. For example, we used the Dictionary of Occupational Titles (DOT) codes and a study conducted for us by the American Federation of Information Processing Societies of <u>Occupational Taxonomies for Computer Specialists</u> to expand Standard Occupational Classification (SOC) codes for computer specialists.**
>
> **As we finalize our questions, we will consult with other Federal agencies. We have, for example, arranged to sit on any future Standard Occupational Code committees in order to work towards uniform occupational coding of S&E occupations. We have also played a lead role in developing classifications in the S&E area for OPM data.**

<u>Recommendation 5.3</u>. Currently, the primary goal of the NSF data system is to provide information on the characteristics of science and engineering personnel in order to support the planning processes of government, academic, and business institutions. In the 1990s, the data system should continue to serve this goal. Specifically, the system should:

- Support the preparation of regular profiles of the characteristics of scientists and engineers, including their numbers, employment patterns, qualifications, utilization, and other characteristics, with separate tabulations by field, sex, and race when feasible and

- Support the preparation of special analyses that illuminate specific policy issues and characteristics of science and engineering personnel in greater depth.

In the 1990s, the data system should also serve other important goals to which NSF does not currently accord high priority. Specifically, the data system in the 1990s should:

- o Provide a research base for improved analysis of relevant labor markets and of flows into, out of, and within the science and engineering labor force that can pinpoint trouble spots and provide early warnings of future problems and

- o Provide a data base that will support basic innovative research on scientists and engineers and the science and engineering education pipeline.

STATUS: We agree with the goals that CNSTAT articulated in this recommendation. The 1990s STPDS is being designed to meet our primary goal of providing information on the characteristics of science and engineering personnel. We are also working on ways to improve the research utility of our data.

Improving the research community's access to the STPDS data is also an important goal. We have recently revised our data access policy so that researchers are able to use data from the Survey of Doctorate Recipients under controlled conditions designed to preserve the privacy of our respondents. Two researchers have already taken advantage of this opportunity. Not only has this made the data more available, but the researchers involved have provided us with important feedback on technical survey issues and ways to improve the policy relevance of the data.

The many improvements to the STPDS which are detailed throughout this report should provide researchers with much improved data in the 1990s compared to the 1980s. This is, of course, of fundamental importance to all research based upon the data.

Recommendation 5.4. NSF should provide information about the full range of people who can be considered as part of the science and engineering supply. NSF should furnish information on the population of graduates in science and engineering fields, not all of whom have related work experience. NSF should also furnish information on the population of employed scientists and engineers, not all of whom were trained in science and engineering fields. NSF should discard the current screening algorithm as a means of defining the population. Instead, NSF should use definitions based on standard occupation and degree field categories, developing within these frameworks more richly detailed classifications of subgroups of scientists and engineers.

STATUS: We agree that the screening algorithm used in the 1980s was conceptually confusing and should be replaced. It was designed to reflect the diversity of definitions used by professional societies in defining who was or was not a member of the various S&E fields. However, as noted in the CNSTAT report, it was difficult for casual users to understand.

NSF will discard the current screening algorithm and use a set of definitions based on standard occupation and degree fields. We expect that the STPDS of the 1990s will provide us with fairly comprehensive information about the population with S&E degrees. The Postcensal Survey will also provide information about individuals in the relatively small segment of the population who are employed in science and engineering occupations, but who do not hold degrees in science or engineering.

Changing the definition of the S&E population will require us to deal with the consequent discontinuity between the 1980s and 1990s STPDS estimates. We have included assistance with crosswalking the 1980s and 1990s series in our contract with MPR in order to minimize the disruptions to the time-series.

Recommendation 5.5. NSF should increase the research utility of the science and engineering personnel data base by enriching the content of its surveys. NSF should assign priority to new or modified content items that will provide greater understanding of:

- o The kinds of work that scientists and engineers do and how their work is changing in response to changes in technology, organizational structure, and other factors;
- o The career paths that scientists and engineers follow and the factors that influence key transitions, including initial entry into the labor force, mobility across fields and sectors, and retirement; and
- o The productivity that scientists and engineers achieve and how their accomplishments relate to characteristics of their training, career moves, and work environment.

STATUS: As part of the process of designing the questionnaires for the STPDS of the 1990s, MPR and NSF staff have carefully considered these goals. We have

- o reviewed past STPDS questionnaires and relevant questionnaires prepared by other agencies;

- consulted with STPDS users, experts on research and questionnaire design, and STPDS contractors through both formal group meetings and more informal contacts; and

- searched appropriate literature.

The 1990s questionnaires will provide a much richer source of information on the above issues than the 1980s instruments did. However, implementation has necessarily been limited by the following factors:

(1) Many of the concepts stated in this recommendation are very broad. Translating broad concepts into concrete questions that are easily understood by respondents is a challenging task that cannot always be accomplished within the constraints of a mail questionnaire. For example, even after many hours of discussion with experts from a variety of fields and performing relevant literature searches, we have not been able to find a satisfactory way to measure productivity that would be applicable to the entire S&E population. Response to this problem will require special studies.

(2) Some concepts that are of interest to us are not best measured in a survey of individuals. For example, information on S&E employment by type of industry (Standard Industrial Code classification) is more accurately provided by employers than by employees.

(3) Respondent burden is another real and practical concern. There will always be more questions of interest than can be included in one questionnaire.

Based on our work to date, we believe that the STPDS of the 1990s will greatly enhance researchers' ability to study many highly important content areas such as: the career paths of individuals with S&E educations; occupational mobility; dual wage earners; and ways in which S&E personnel have been updating their skills. Enrichment in other issue areas will be more limited.

Recommendation 5.6. NSF should conduct a large Postcensal Survey of College Graduates in 1992 based on the 1990 decennial census that provides baseline information on college graduates, includ-

47-644 O - 91 - 6

ing those who are trained in science and engineering fields and those with employment in science and engineering occupations.

> **STATUS:** We are proceeding with plans to conduct a Postcensal Survey of 150,000 College Graduates. Our plans for the survey include enhancements to the questionnaire, the statistical design, and the data collection techniques, which should result in major improvements in the 1990s survey compared to that conducted in the 1980s.
>
> **We expect to field the survey in 1993 instead of 1992. Our decision to delay fielding for a year was based in part on problems that arose in the 1982 Postcensal Survey, which might have been avoided if we had delayed sample selection until 1983.**
>
> **We recognize that the delay in fielding the Postcensal Survey may adversely impact response rates. However, we expect to minimize the negative impact of the delay by using the National Change of Address (NCOA) file, produced by the Post Office, to update addresses for our sample members. Further, the delay in fielding will permit us to conduct a pretest of the methodology and survey instrument we plan to use for the Postcensal Survey. We expect that improvements suggested by the pretest will more than compensate for any negative impacts of the delay.**

Recommendation 5.7. NSF should conduct a Panel Survey of Scientists and Engineers that periodically provides updated information on the population of college graduates with science and engineering degrees and that tracks the 1992 cohort of graduates with employment in science and engineering occupations, including those who were trained in other fields. The survey should include cases drawn from the Postcensal Survey. The survey should also include a sample for each new graduating class that is drawn from Prospective Graduate Surveys conducted each year of students at higher education institutions who are about to receive a bachelor's or master's degree in a science or engineering field.

> **STATUS:** NSF plans to conduct a biennial Panel Survey of college graduates, starting in 1995. Individuals will be selected for this survey from both the Postcensal Survey and the Survey of Recent Graduates. This survey will provide good coverage of the population with S&E degrees from U.S. postsecondary institutions. It will also permit us to track the cohort of 1993 graduates with S&E degrees from foreign institutions and those employed in S&E occupations in 1993 who have non-S&E degrees.

The segment of the 1995 panel survey covering recent graduates will be drawn from our Survey of Recent Graduates rather from a Prospective Graduate Survey, as recommended. We have discussed the possibility of interviewing students prior to graduation with personnel from a number of colleges. They were very skeptical about the feasibility of such a survey. Especially for Master's degree recipients, it is not always easy to determine who will be graduating much in advance of graduation. Further, students who are about to graduate are in the midst of major life decisions that college personnel believe are likely to impede their cooperation.

Conducting a full-scale survey solely for the purpose of establishing a sample frame is also a very costly way to increase response rates. We are working with our survey contractor (Temple University), our redesign contractor, and our technical working group on alternative ways, such as the use of NCOA, to improve our response rates in 1993. If we fail in 1993 to obtain an acceptable response rate for recent graduates, we will reconsider our decision to do a Prospective Graduate Survey.

Recommendation 5.8. NSF should continue to support the ongoing Survey of Doctorate Recipients and employ it as the major source of information on science and engineering personnel trained to the Ph.D. level. The SDR should be modified to facilitate its use with the other surveys in the NSF science and engineering personnel data system.

STATUS: NSF continues to support the SDR. Many of the changes recommended by the CNSTAT panel will be implemented in the 1991 SDR. These improvements include a reformatted questionnaire design, a substantial Computer Assisted Telephone Interview (CATI) follow-up of nonrespondents, intensive respondent tracking activities and personalization of the mailings.

Standardization of questions in the SDR to make them compatible with the other STPDS surveys will be implemented in 1993. We made only minimal changes to the 1991 survey, because pretesting of the 1993 questions is not yet complete and we do not wish to introduce changes in two successive survey waves, since this would make time-series analyses difficult.

Recommendation 5.9. To the extent possible during the decade, NSF should use other federal data sources to obtain information on components of the science and engineering population that are

not covered in the NSF survey system and to evaluate NSF's survey-based estimates.

STATUS: **NSF has for a long time performed secondary analyses based upon data collected by other federal agencies. For example, we analyze data about recent S&E immigrants provided by the Immigration and Naturalization Services (INS) and we analyze Office of Personnel Management (OPM) federal S&E personnel data. We also cosponsor the Bureau of Labor Statistics' Occupation Employment Statistics survey.**

SRS and MPR staff have met with representatives from the Census Bureau to discuss both the Current Population Survey and the Survey of Income and Program Participation in order to improve our coordination and to discuss the possibility of adding relevant questions to these surveys to facilitate compatibility between NSF and Census surveys. We will increase our focus on this aspect of the redesign after we come to closure on the more immediate planning issues.

Recommendation 5.10. Because of the importance of degree field in defining the population of scientists and engineers, the Current Population Survey should periodically include a supplement that asks respondents for major field of bachelor's and higher degrees. NSF should work for the adoption of this recommendation by the Bureau of Labor Statistics and the Census Bureau.

STATUS: As indicated above (5.9), we have started discussions with the Census Bureau on this issue.

Recommendation 5.11. NSF should pursue its planned research program to develop estimates of immigration and emigration of scientists and engineers and to develop ways of incorporating such estimates into the personnel data system.

STATUS: With the cooperation of INS, Oak Ridge Associated Universities conducted a pilot survey of recent immigrants for us. Based on the results of their evaluation, NSF has concluded that it is not currently feasible to design a cost-effective survey to provide information about immigrants who are educated as scientists and engineers.

The primary obstacle to the successful completion of a survey of immigrants with S&E educations is that INS does not collect information on the level and field of education as part of their standard administrative record keeping. Therefore, to interview all those educated in S&E, we need

to select cases from the entire recent immigrant population.

Our pilot survey indicated we could probably obtain a reasonable response rate from a mail/telephone survey of individuals whose INS records indicated that they had S&E or administrative occupations. However, the pilot survey response rate for the remainder of the sample was extremely low (under ten percent). While we believe we could substantially improve the response rate of the pilot survey by appropriate methodological changes, we do not believe we could obtain an acceptable response rate unless we conducted in-person interviews, using multilingual interviewers. We believe the cost of such interviews would be prohibitive.

We have initiated discussions with INS about the feasibility of their collecting information on the level and field of education of new immigrants. This would provide basic information of use to us and would increase the likelihood that we could design a cost-effective survey to obtain additional information. Such a change would also provide INS with information of relevance to the implementation of recent changes in the immigration laws.

In addition to our work on a potential survey of recent immigrants, we have been evaluating ways of making the other STPDS surveys a more fruitful source of information about immigrants and emigrants. For example, in our sample design work we have explicitly incorporated place of birth into our stratification scheme for the Postcensal and SDR samples in order to ensure sufficient cases for analyzing this population.

Recommendation 5.12. NSF should consider the study panel's recommended design for its science and engineering personnel data system in the 1990s as a package in which basic information on the population of scientists and engineers, detailed information on topics and subgroups of key analytic interest, and evaluation and augmentation of NSF's own survey estimates using other federal data sources are integral and equally important elements.

STATUS: NSF has been taking a systems approach to its design work for the 1990s. For example, we recently completed the draft questionnaire for the Postcensal Survey questionnaire pretest and have provided MPR with preliminary specifications for developing questionnaires for the New Entrants and SDR surveys. The specifications were written in terms of questions which should be added to or deleted from the Postcensal Survey in order to accommodate the unique needs of the survey populations. This approach assures the existence of "core" questions for all the surveys.

The redesign planning work at NSF has involved a team approach. For example, during the development of the Postcensal Survey questionnaire all STPDS professional staff have participated in bi-weekly meetings to discuss question development. This process has encouraged a systems approach to the STPDS.

The team approach has also been extended to the survey contractors responsible for the individual STPDS surveys. We have periodically met the contractors to update them on plans for the 1990s and to ensure their understanding of the systems approach we are using.

Recommendation 6.1. In order to conserve resources and reduce burden on higher education institutions, NSF and the National Center for Education Statistics should design a unified sampling frame and coordinate procedures for obtaining data on prospective college graduates. The two agencies should not combine their panel surveys of new graduates, however, which serve different purposes and focus on different fields of training. Key questionnaire items should be comparable in order to permit each agency to evaluate and supplement its own data with data from the other agency.

STATUS: As explained above (Recommendations 5.7), we do not currently plan to conduct a Prospective Graduate survey. Based on discussions with NCES we have concluded that the overlap in sample frame, timing needs and questions between the NCES surveys and our surveys is not sufficient to justify the expense of using a coordinated sample frame.

Recommendation 6.2. NSF should initiate modifications to the Survey of Doctorate Recipients, specifically, in the areas of coverage, survey scheduling, sample design, and wording of key questionnaire items, that will improve comparability of the SDR data with other data in the NSF science and engineering personnel data system.

STATUS: The 1991 SDR will be modified in order to make its coverage more comparable to the New Entrants survey. Both surveys will restrict their coverage to individuals with S&E degrees from U.S. universities. Information about individuals who have S&E degrees from foreign Universities will be obtained from the Postcensal Survey.

Starting with the 1993 surveys, we plan to field all STPDS surveys at the same time in order that the same reference month can be used for all of them.

In conjunction with several highly qualified statistical consultants, NSF staff have been evaluating the sample designs for all the STPDS surveys. MPR has also been developing computer software to assist us in implementing these designs. We believe this process will ensure that sample designs among the surveys are as compatible as possible, given the differences in sample frames among the surveys. The 1991 SDR will be the first survey to be redesigned using this process.

As discussed above (Recommendation 5.12), all our 1993 survey questionnaires will include "core" items which will be the same for the SDR as the other surveys.

<u>Recommendation 6.3</u>. Detailed specification of the design for the NSF personnel data system in the 1990s will require additional analysis and decision making. NSF should in the near term set in place a process for reaching final design decisions. The process should include:

- o Identifying and funding priority research and analysis projects whose results are needed to inform the design;
- o Establishing a group of technical experts to work with NSF staff in reaching final design decisions and to assist NSF in monitoring the operation of the system in the 1990s; and
- o Sponsoring workshops and in other ways seeking both to obtain input from users and to advise them of impending changes in the data system.

<u>STATUS:</u> Assistance with these tasks has been obtained through the contract with MPR. Two technical working groups have been set up: A content group of representatives from academia, industry, and professional societies; and a methodology group of experts in various aspects of survey design. Both groups have met formally, and individuals from the groups are consulted as needed. In addition, relevant research has been conducted by SRS contractors, including studies of nonresponse bias for the SDR and New Entrants Surveys and the pilot survey on immigrants.

<u>Recommendation 6.4</u>. Toward the end of the 1990s, NSF should conduct a thorough, zero-based evaluation of the design and operation of its personnel data system to determine whether to continue the basic design of the 1990s or to change the system in important ways. The evaluation should include a review of the goals of the system and the extent to which the informational content is serving these goals.

STATUS: NSF will make plans to conduct such evaluations.

Recommendation 7.1. NSF should develop a quality profile for its personnel surveys that will guide the development of an effective system to monitor and maintain data quality and suggest research to learn more about sources of error in the data and to identify further possible improvements.

STATUS: Nonresponse studies for the 1989 SDR and the 1990 New Entrants Surveys have been completed. The MPR contract includes a task to develop a standardized format for Quality Profiles for the STPDS surveys of the 1990s.

Recommendation 7.2. NSF should take advantage of the experience of other federal statistical agencies in developing quality profiles, setting quality standards, and implementing quality control programs. NSF should keep abreast of procedures and techniques that federal agencies and private survey research centers use for improving quality, particularly of data from continuing panel surveys.

STATUS: NSF's understanding of the work at other federal statistical agencies on quality standards and quality control has been enhanced by our recent hire of individuals from other federal agencies. NSF officials have also discussed these issues with high level personnel at other federal statistical agencies. More formal work on these tasks will be undertaken as part of our redesign work with MPR.

Recommendation 7.3. NSF should devote a significant portion of its budget each year for the personnel data system to quality review and improvement activities.

STATUS: The redesign process has entailed considerable work and expense on tasks such as non-response studies and our pretest of the Postcensal Survey, which entail reviewing and improving the quality of the personnel system data. We also plan as part of the redesign process to implement an on-going program of studies related to quality control issues. Recommendations for this program are included in the redesign tasks within our contract with MPR.

Recommendation 7.4. When faced with budget constraints that necessitate trade-offs, NSF should choose options for the system that minimize total error in the data, taking into account both sampling error and nonsampling error from sources such as nonresponse.

STATUS: Our commitment to this tenet was demonstrated recently in our decisions with respect to the 1991 SDR. Faced with higher than anticipated costs for the survey, NSF opted to make needed improvements in survey methodology even though this required us to cut the sample size. We believe that the reduction in response bias engendered by this approach will lead to a lower total error than would have been true if we had maintained sample size but postponed some of the needed survey improvements.

Our commitment to improving the STPDS was also reflected in our decision not to field a 1991 Survey of Experienced Scientists and Engineers. We decided that the problems which exist in this panel survey precluded an acceptable response rate in a 1991 survey.

Recommendation 7.5. NSF should adopt the best survey practice in designing and evaluating questionnaires for its science and engineering personnel surveys.

STATUS: NSF's commitment to adopting best survey practices in designing and evaluating questionnaires is reflected in the care with which we are developing our Postcensal Survey Questionnaire. In addition to getting feedback on questions from our users and from our technical working group, we have asked the Census Bureau to do a formal pretest of the Postcensal Survey questionnaire and have asked MPR to conduct focus groups on particularly difficult questionnaire issues.

Recommendation 7.6. NSF should adopt the best survey practice for its personnel surveys in the following operational areas:

- Procedures for obtaining high levels of response, both through initial contact and follow-up;
- Procedures for data preparation, including developing appropriate weights, imputing missing values, and editing the data for consistency.

STATUS: MPR has completed its report to us on data collection methodology. Based on MPR's work and the nonresponse study for the 1989 SDR survey, we believe that the nonresponse problems for the SDR can be solved by devoting greater resources to tracking cases, telephone follow-up, and other survey design features. We plan to implement most of these improved procedures in the 1991 SDR.

The solutions to the nonresponse problems in the New Entrants and Postcensal surveys are not as straightforward;

however, we plan to implement a number of improvements to increase response rates.

We plan to use the National Change of Address data file to verify and update addresses prior to first mailings for the Postcensal and New Entrants surveys. We will be testing this methodology in the Postcensal Survey pretest and also with a small sample of non-respondents to the 1990 New Entrants survey.

Because of the crucial importance of the Postcensal Survey to the success of the STPDS, we will be testing the efficacy of using personal visits for individuals who do not respond to either the mail or telephone follow-up in our pretest. If the pretests prove that personal visits are necessary in order to obtain an acceptable response rate to the Postcensal Survey, we are prepared to use the same methodology in the Postcensal Survey. We will also retain those individuals identified in the Postcensal Survey as having S&E education or employment throughout the decade, even if they fail to respond to early waves of the panel survey.

Recommendation 7.7. NSF should provide resources to the Science Resources Studies Division for staff training in survey methodology and for staff to attend conferences, short courses, and other venues of continuing education. NSF should also provide resources for the staff to develop firsthand knowledge, through field visits and other means, of the many different kinds of scientists and engineers whose characteristics the personnel surveys are intended to measure.

STATUS: Within our budget constraints, staff have been able to engage in some formal developmental activities. For example, STPDS staff are taking part in developmental programs sponsored by the American Statistical Association. Courses are also planned for appropriate staff in the use of statistical computer programs. This formal training has been supplemented by considerable informal training activities in which STPDS staff have shared skills and knowledge obtained by their varied backgrounds.

Recommendation 7.8. NSF should provide resources for the staff of the Science Resources Studies Division to have access to the personnel microdata. NSF should encourage the staff to use the data for analytical studies, particularly those that relate to data quality and methodology, and to present their findings at professional meetings and in professional journals.

<u>STATUS</u>: NSF staff currently have access to microdata files. Due to the heavy demands of the redesign efforts, limited time has been available for analytical efforts.

<u>Recommendation 7.9.</u> NSF should include resources in its survey contracts for contractors to propose and carry through research related to understanding and improving data quality.

<u>STATUS</u>: As indicated above (e.g., Recommendation 7.3), NSF has recently funded non-response studies. Additional experimental work has been incorporated into recent contracts aimed at evaluating ways in which response rates could be improved.

<u>Recommendation 8.1.</u> NSF should plan an extensive publication program from the 1992 Postcensal Survey, which will provide the first comprehensive look in a decade at the entire population of scientists and engineers and permit comparative analysis with other subgroups of college graduates.

<u>STATUS</u>: We believe that this should be a major goal of the Postcensal Survey and plan to determine the best way of accomplishing it.

<u>Recommendation 8.2.</u> As a major publication series from the continuing Panel Survey, NSF should regularly publish profiles of college graduates with science and engineering degrees that separately identify important subgroups to permit users to apply a narrow or broad definition of the population as suits their needs. Two basic tabulation series would be useful: one series that focuses on the current employment situation of people with degrees in particular science and engineering fields, and another that focuses on the educational background and work environment of science and engineering graduates who are employed in particular science and engineering occupations. NSF should also produce publications from the Panel Survey about the cohort of employed scientists and engineers (including people trained in other fields) identified in the 1992 Postcensal Survey and about new graduates in science and engineering fields.

<u>STATUS</u>: We agree with this recommendation and have made some preliminary steps towards providing a transition from our current tabulations to the recommended tabulations in our 1990 report to Congress on <u>Women and Minorities in Science and Engineering</u> and in our publication based on the 1989 Survey of Doctorate Scientists.

Recommendation 8.3. In determining the categorization of degree field, occupation, and other variables in NSF tabulations, user needs for more information must be balanced against considerations of sampling error. NSF should set standards for the minimum size science and engineering field for which estimates will be published based on the error properties of its surveys. Conversely, NSF should seek meaningful ways to provide additional detail for larger science and engineering fields.

STATUS: We have discussed publication criteria with Census Bureau and BLS. Based on their standards we believe that setting a minimum sample cell size of 50 for publication is appropriate. We are currently using this standard in designing the sample for the 1991 SDR.

Recommendation 8.4. NSF should provide a variety of products from the personnel data system -- printed reports, public use microdata files, and other computer-readable products -- that serve the needs of the entire user community, ranging from those users who require a few specific numbers to those users who are engaged in extensive analysis.

STATUS: MPR will be working with us on the task of how to make our materials more accessible to the public. This contract task is scheduled after the survey redesign tasks are completed.

Recommendation 8.5. NSF should implement the recommendations that are developed by the Committee on National Statistics from its recent effort to seek ways to improve research access to the Survey of Doctorate Recipients while protecting the confidentiality of individual replies.

STATUS: At NSF's request, NRC has prepared SAS data tapes for both a public use and a limited access tape for the 1989 SDR. Procedures are in place for researchers to use the limited access tape at SRS and have recently been utilized by two academic researchers. We have in place procedures that will preserve the privacy of respondents.

Recommendation 8.6. NSF should provide complete documentation for all products made available from the personnel data system, including a comprehensive user's guide to accompany public use microdata files. Data file documentation and technical notes included in publications should emphasize the nature and likely magnitude of the errors in the data.

STATUS: SRS is working to improve its documentation on all personnel data products. NRC has, for example, prepared

documentation for the SDR microdata files, which was found to be highly useful by the first researcher who used the limited access file. SRS is also placing an increased emphasis on providing users with information about sampling and non-sampling errors in its publications.

Recommendation 8.7. NSF should actively publicize the availability of public use microdata files and other products from its personnel surveys.

STATUS: We have been working with National Technical Information Service (NTIS) to obtain its assistance in this regard and have included assistance with outreach as a task in the MPR contract.

Recommendation 8.8. NSF should actively encourage and provide support to researchers for innovative studies of science and engineering personnel using the survey microdata. NSF should consider for this purpose establishing a grants program to fund projects that use the personnel data.

STATUS: We have not established a formal program to obtain this objective. However, the Division of Social and Economic Sciences (BBS) funded one of the researchers who has used the SDR limited access tape. BBS is also funding research on methods to estimate the supply and demand for U.S. scientists and engineers.

Recommendation 8.9. NSF should actively solicit feedback from its users on the design, content, and quality of the data system, and on the content and format of data products. NSF should consider for this purpose establishing a user panel to provide input on a regular basis.

STATUS: Under our contract with MPR we have established technical working groups to provide input from users needed for the redesign of the STPDS.

Mr. BOUCHER. Thank you, Dr. Brown.

Dr. Liebman, we'll be pleased to hear from you.

STATEMENT OF JUDITH LIEBMAN, VICE CHANCELLOR FOR RESEARCH AND DEAN OF THE GRADUATE COLLEGE, UNIVERSITY OF ILLINOIS AT URBANA, CHAMPAIGN, ILLINOIS AND CHAIRMAN, NSF ADVISORY COMMITTEE, DIVISIONS OF POLICY RESEARCH AND ANALYSIS AND OF SCIENCE RESOURCE STUDIES

Dr. LIEBMAN. Mr. Chairman and members of the committee, I am pleased to have this opportunity to testify. As you know, I chair the NSF Advisory Committee on Data Policy and Analysis. This committee was appointed to provide NSF advice on a variety of issues related to the collection and evaluation of data, the data that related to our country's science and engineering enterprise. You've asked me to comment on NSF's response to the NRC report. Our committee has not yet had an opportunity, as a committee, to review the formal document describing NSFs responses. Our committee has, however, discussed a variety of issues related to the concerns expressed in the NRC Report, and I will briefly summarize these discussions for you.

In our committee's opinion, SRS, the division responsible for the data collection and evaluation, is not yet budgeted to respond instantaneously to all the recommendations. Thus, they have needed to prioritize their responding actions, and they have done so. Our committee concurs completely with the NRC Report, the quality control and the collection, reporting and analysis of data, as essential, and that there are many ways to improve quality.

An outstanding example of quality in data collection and evaluation lies in the Federal collection and the reporting of labor statistics. Thus, our committee asked Dr. Janet Norwood, U.S. Commissioner of Labor Statistics, how they achieved their level of quality. She indicated that major aspects of their quality control procedures include providing extensive access to the data, providing data documentation with complete detail on how the data were collected and analyzed, and carrying out extensive internal and external reviews before data or publications are released.

However, she observed that there is a major difficulty in providing complete access to the data with respect to data that can be identified with an individual. That individual must remain unidentifiable. Dr. Norwood described this aspect as a major challenge of the 1990s, developing ways to provide access to as much of the data as possible while retaining confidentiality with respect to individuals.

The committee has also discussed the uses of these data systems. A major use is to support forecasting the availability of scientific and engineering personnel. However, we are discovering that forecasting this availability is not an easy matter. Why individuals chose to make, or not to make, these career choices is much more complex than we had realized.

In response to this need to improve our ability to forecast and to staff, as Dr. Brown has indicated, BBS has solicited proposals to study how to determine the supply and demand of scientists and engineers. This research is urgently needed not only to improve

our ability to forecast, but to enable us to better understand the pipeline and why so few individuals survive the pipeline.

We need to attract more women and minorities into science and engineering, but our ability to do so is currently limited. I personally majored in physics as an undergraduate and in an engineering field as a graduate student. But to this day, I can't tell you why I made it through the pipeline and others did not.

In closing let me say that the NRC Report was extraordinarily well done, the best report of that kind I have ever seen. And in my opinion, NSF is being full—within their budget—is being fully responsive to these recommendations.

Thank you very much for this opportunity to testify, and I will be happy to answer questions.

[The prepared statement of Dr. Liebman follows.]

TESTIMONY

OF

JUDITH S. LIEBMAN
Vice Chancellor for Research
and Dean of the Graduate College
University of Illinois at Urbana-Champaign

BEFORE THE

SUBCOMMITTEE ON SCIENCE

OF THE

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

CONCERNING

NSF'S DATA COLLECTION AND EVALUATION ACTIVITIES

FOR SCIENTIFIC AND ENGINEERING PERSONNEL

JULY 31, 1991

NSF'S DATA COLLECTION AND EVALUATION ACTIVITIES FOR SCIENTIFIC AND ENGINEERING PERSONNEL

Mr. Chairman and Members of the Subcommittee on Science, I am Judith Liebman, Vice Chancellor for Research and Dean of the Graduate College at the University of Illinois at Urbana-Champaign. I am pleased to have this opportunity to testify on NSF's data collection and evaluation activities for scientific and engineering personnel.

I chair the NSF Advisory Committee on Data and Policy Analysis. Members of this committee are listed in an appendix to this testimony. This committee was established by the Scientific, Technological and International Affairs (STIA) Directorate of NSF in January, 1991, and has met twice. It is chartered by NSF to: 1) review and advise on current and emerging science and technology issues, problems and opportunities related to data and policy analysis; 2) suggest data and analyses that would be most useful in addressing the issues, problems, and opportunities identified, and appropriate techniques for their collection and dissemination; 3) provide on request suggestions for changes and improvements that would assist in serving the needs of users; and 4) recommend issues of concern to the Divisions, the STIA Directorate, and the Foundation that deserve more detailed attention.

The committee was provided the National Research Council (NRC) report Surveying the Nation's Scientists and Engineers: A Data System for the 1990s but has not yet had an opportunity to discuss NSF's recently updated response. Nevertheless, the committee has discussed a variety of issues related to the concerns expressed in the NRC report.

The committee believes that the Science Resource Studies Division (SRS) is not currently budgeted to respond fully to the concerns expressed in the NRC report. SRS will have to develop priorities when implementing actions in response to the report recommendations. Our committee is in a good position not only to comment on SRS's responses to the report, but also to comment on the associated priorities.

The committee concurs completely that quality control in the collection, reporting, and analyses of data is essential, and that there are multiple mechanisms and policies through which improved quality can be achieved. In a presentation before the committee, Dr. Janet Norwood, U.S. Commissioner of Labor Statistics, stressed the importance of publishing (in printed form or making available in electronic form) not only the data (in as fine detail as possible, given confidentiality requirements) but also the detailed methodologies by which the data were collected and analyzed. Such publication provides the opportunity for public scrutiny and assessment and is an extremely important quality control mechanism.

However, when data related to individuals are in the database, complete openness becomes impossible.

One of the NRC report recommendations was that the data system should "Provide a research base for improved analysis of relevant labor markets and of flows into, out of, and within the science and engineering labor force that can pinpoint trouble spots and provide early warnings of future problems." Developing forecasts of the availability and employment of science and engineering personnel has turned out to be extremely complex. There appear to be complicated societal, economic, and personal factors involved, none of which do we yet completely understand. Dr. Mary Clutter, Assistant Director for Biological, Behavioral, and Social Sciences (BBS) at NSF, was invited by the committee to discuss the role of BBS in supporting research related to the collection and analysis of social and economic data. The committee was pleased to learn of the proposed solicitation for proposals to study how to determine the supply and demand of scientists and engineers.

I have reviewed NSF's recently updated response to the NRC report and believe that SRS's proposed actions are on target. SRS is appropriately addressing the most urgent needs first: reworking the core instrument of the Scientific and Technical Personnel Data System (STPDS) for the 1990s, developing the 1992 Postcensal Survey, and improving the Survey of Doctorate Recipients. SRS has contracted for, received, and accepted expert advice on a variety of technical issues, including improving quality and increasing response rates.

In addition to discussing NSF's response to the NRC report, our committee also will be learning how the personnel and industry R&D support data systems are constructed, assessing whether the SRS data and reports are fully capturing the activities of U.S. R&D enterprises abroad and foreign enterprise R&D activities in the U.S., exploring how SRS data activities need to evolve in order to meet future needs, and weighing emerging policy issues and evaluating how they relate to the currently available data.

Thank you for this opportunity to testify. The NRC report was an exceptionally well-done analysis of what needs to be done to improve NSF's Science and Engineering Personnel Data System. I am confident that NSF is responding appropriately and fully to its recommendations.

APPENDIX

The NSF Advisory Committee on Data and Policy Analysis

Dr. Judith Liebman,	University of Illinois at Urbana-Champaign, IL Chair
Mr. Jesse Ausubel,	Carnegie Commission on Science, Technology and Government, Rockefeller University, New York, NY
Dr. Janice Beyer,	University of Texas at Austin, TX
Dr. Kenneth Flamm,	Brookings Institution, Washington D.C.
Dr. Alan Goldman,	The Johns Hopkins University, Baltimore, MD
Dr. William Howard,	National Academy of Engineering, Washington D.C.
Dr. Albert Link,	University of North Carolina at Greensboro, NC
Mr. Hugh Loweth,	Consultant, Washington D.C.
Dr. Stephen Lukasic,	TRW, Space and Defense Sector, Redondo Beach, CA
Dr. Robert Morgan,	Washington University, St. Louis, MO
Dr. David Mowery,	University of California at Berkeley, CA
Dr. Richard Nicholson,	American Association for the Advancement of Science, Washington D.C.
Dr. Merrill Shanks,	University of California at Berkeley, CA
Dr. Edward Tufte,	Yale University, CT
Ms. Katherine Wallman,	Council of Professional Associations on Federal Statistics, Alexandria, VA

Mr. BOUCHER. Thank you, to both of the witnesses, for your statements here this morning.

Let's address the question of resources. We had this discussion to some extent with the previous panel.

Dr. Brown, Dr. Liebman, what is your opinion of the adequacy of the resource level currently available to NSF for the purpose of data collection, analysis, and dissemination, with regard to the adequacy of the scientific and engineering work force?

Dr. Brown?

Dr. BROWN. Well, Mr. Chairman, adequate resources is a very difficult question in survey work. There are always opportunities to spend some more money to get more information, and we find it a very difficult problem to determine just when we've reached the point when the marginal benefits are worth the extra dollars. The data on scientists and engineers will always be costly, as Dr. Dauffenbach indicated. When you have a group of people that's only a small portion of the population, it's awfully hard and expensive to find out a lot about them. If you go out and sample the population unrestricted, 29 out of the 30 people in your sample won't have anything to do with science and engineering, and you've spent a lot of money.

Now, getting more specifically to our budgets, I think you know that people at my—in my position are not fully empowered to discuss their budgets because that goes through the budget process, thanks to the Budget and Control Act of 1924, I think it was.

Now, I will say this. The budget that is now in preparation is the fiscal year 1993 budget, that is—I'm not sure if that's gone to OMB or not, but it's certainly is a long way from going to Congress. 1993 also happens to be a year when we plan to do our postcensal survey—that's the most expensive thing we do—plus two other surveys. The new entrants and the survey of doctoral requirements will come up again in that year. That's going to be a big year of spending for us—or at least for a small bureau like ourselves.

And I have talked to the people in NSF at the highest levels, and I do say—I can say that we have agreed in principle that a fairly sizeable increase will be requested for fiscal year 1993. And I would say we have received all assurances that can be reasonably made at this point that the required funds will be in our proposed budget that goes to Capitol Hill.

Mr. BOUCHER. Will that funding give you the resources—assuming approval of the budget request that you make—will you then have the resources necessary to carry out the recommendations of the NRC Report?

Dr. BROWN. We will have the resources to carry out the part of the report that says, work smarter, have better survey designs, work faster, get your work out. Now, as I indicated in my testimony, where it gets expensive is when you attempt to increase the size of the sample. There you start running up millions of dollars on the cash register before you know it. I would have to go back and see how much of their report dealt specifically with sample size. I do note that Dr. Dauffenbach, this morning, made a plea for, I think he said, about a three times—

Mr. BOUCHER. Three-fold increase in sample size.

Dr. BROWN. There is no way that that will happen. I think our sample sizes will be somewhere in the ball park of what they have been in the past. But, again as I have indicated, our improvements in technique, I think, will make the surveys better—much better for that reason.

Mr. BOUCHER. What would you estimate that it would cost to triple the sample size that the NSF obtained?

Dr. BROWN. Triple the sample size.

Mr. BOUCHER. If his recommendations were to be put into place what would that cost?

Dr. BROWN. Yes, that's—well, let's see now. Let me do a little bit of mental arithmetic. If we're talking about—in 1993, sample sizes—this is going to be rough. I mean we're talking in the low hundreds of thousands of people, maybe a hundred—triple it, that adds, oh, 200,000. Multiply that by $50 and you've got—200,000 x 50 is a million—$10 million.

Mr. BOUCHER. To triple the sample size?

Dr. BROWN. Something like that, in other words—

Mr. BOUCHER. Did the NRC Report recommend any increase in your sample size?

Dr. BROWN. I'm sure they did from time—I'm sure they did from time to time.

Mr. BOUCHER. You don't recall off hand what that recommendation is?

Dr. BROWN. I can't give you the exact number, but I know that in the report in various places, especially when they were talking about getting more information on certain particular groups, they did recommend larger sample size.

Mr. BOUCHER. That is not one of the recommendations, I gather then, it is your intention to carry out?

Dr. BROWN. You've got me on the spot, Mr. Chairman. I'll have to respond—I'd rather respond for the record on that looking at their specific recommendations rather than saying we are not taking them, because I am quite confident—as I went over this report page by page, I found myself saying, we are taking virtually all of their recommendations, and those that we are not taking are—

Mr. BOUCHER. I'll come back to that answer. Let me—Dr. Liebman is seeking recognition here.

Dr. LIEBMAN. It doesn't make sense, it seems to me, to expand these sample sizes to much larger sizes without taking advantage of those samples for other information. And the suggestion that came out in the earlier panel this morning on doing a broader—on looking for a broader base of information. I think they mentioned a college survey where you get a broader base of information so that you are not just looking for scientists and engineers, you have—and the much larger samples will enable you to get much more information on women and minorities and their career choices, but it's not clear that it is going to be cost effective to do that just for science and engineering.

Mr. BOUCHER. Well, Dr. Brown, let me ask you to do this if you would. Look at the NRC recommendation, specifically with respect to sample size increases. Send to us a written answer, if you would, that indicates your intention with respect to complying with that

recommendation. And to the extent that your budget request needs to be increased in order to accommodate your intention to comply with that increase, let us know what that—what the quantity of increase would be relative to that function, if you would.

Dr. Brown. I will be happy to do that. I'm just reminded in a few words by my colleague sitting behind me, Dr. Carolyn Shettle, that in—that we have met what they call to be, at least, the minimum necessary sample sizes in all cases. So I don't think we are in any violation or disagreement with the report, but it could be—and I'll find this out for you—that in some cases where they recommend a big increase, we probably are not doing that as much as they say.

[The material referred to follows:]

NATIONAL SCIENCE FOUNDATION
1800 G STREET, N.W.
WASHINGTON, D.C. 20550

September 19, 1991

The Honorable Rick Boucher
Chairman, Subcommittee on Science
Committee on Science, Space, and Technology
U.S. House of Representatives
2320 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Boucher:

During your Subcommittee's hearing of July 31, you asked me to respond for the record to a question that I was unable to fully answer at the time. The question was whether we were complying with recommendations by the Committee on National Statistics (CNSTAT) with respect to increases in sample sizes and the potential budgetary costs of complying with such recommendations.

The CNSTAT report does not make specific recommendations about sample sizes for the STPDS surveys. For example, in discussing the Postcensal Survey, CNSTAT says that "NSF should conduct a **large** [emphasis added] Postcensal Survey..." (p.164). However, Chapter 6, on sample design, includes a number of statements which place some boundaries on the sample sizes for the survey with which CNSTAT would be comfortable.

The Postcensal Survey:

Based upon further consideration of the CNSTAT report and recent review of the budget for the Science Resources Studies Division, we are planning to take a sample of between 200,000 and 250,000 cases at an estimated cost of between $11 million and $14 million over a two to three year time span. We state our plans as a range, rather than as a precise figure, because we plan to use evidence on likely response rates derived from a pretest experiment to select the most efficient sample size.

We will be taking a sample considerably larger than the 150,000 cited by the CNSTAT report as the "lower bound for the system." The report is unclear on a recommended sample size; while it cites 250,000 at one point as an "upper bound," it later mentions somewhat higher sample sizes. In any case, we believe our planned sample size is fully consistent with the intent of the CNSTAT report.

The New Entrants Survey:

CNSTAT discussed various sample sizes for the proposed Prospective Graduate survey, ranging from 6,200 to 12,400 for each class. The survey of recent graduates which we plan to substitute for the recommended Prospective Graduate survey should have sample size needs comparable to those recommended for the Prospective Graduate survey. Our planned sample size of approximately 10,500 per class is consistent with the CNSTAT analysis.

The Survey of Doctorate Recipients:

CNSTAT suggested that "a better use of resources might be to specify a somewhat smaller initial sample [than is currently the case] with more effort devoted to obtaining higher response rates and thereby most likely reducing nonresponse bias" (pp. 226-7). At that time the planned sample size for the 1991 survey was 77,300 cases. Our current plans call for a sample of 38,650. The fielding date for the 1991 survey is in October 1991.

Our current budget plans for the 1993 and subsequent surveys should permit us to conduct the SDR with a sample size consistent with that suggested by CNSTAT.

Panel Survey:

The first panel survey selected from the Postcensal and New Entrants surveys is scheduled for FY 1995. As recommended by CNSTAT, we plan to follow all individuals identified in the Postcensal survey who have S&E degrees and/or S&E occupations and will follow a sub-sample of the New Entrants population, selected so that the sampling rate is consistent with the Postcensal survey sampling rate.

I hope that this letter answers your questions.

Sincerely,

Kenneth M. Brown

Kenneth M. Brown
Director, Division of Science
Resources Studies

Mr. BOUCHER. All right.

I've noted also that the NSF is planning to make available some $400,000 in research grants or contracts for research on ways to produce a better means of estimating the appropriateness of supply of scientists and engineers. I'd like for you to elaborate a little bit on the kinds of projects that you expect to have carried out under that $400,000 program, and also indicate to us whether it's your intention to make that a peer-reviewed process where you have an RFP followed by a review by panel, or just what means you intend to go through in awarding those grants and contracts.

Dr. BROWN. Mr. Chairman, I believe you are referring to what I mentioned very briefly in my testimony, the awards program in the Directorate of Behavioral—of Biological, Behavioral, and Social Sciences. That will be carried out in the traditional NSF grant making method, namely they put out a brochure, they told what questions they were asked—interested in. And they had to do with the future of the market for scientists and engineers and the various characteristics. They've already had their competition. They were—I believe they have all been peer-reviewed. The grants have not been made yet, and so I don't know who has received them and who hasn't. But that was carried out in the traditional NSF way with advertisements and quality control all along the way.

Mr. BOUCHER. Could you describe the kinds of projects that you hope to see funded through this initiative?

Dr. BROWN. Well, let me see, they would be basically improving the methods of estimating the supply and demand for scientists and engineers, and looking into—not so much looking into the future and identifying any kind of shortfall, but more the case of modeling in the sense of trying to understand the way the dynamics of the market work.

I refer you to the testimony of Dr. Fechter this morning who is—who discussed this at some length. You know, this is a very old area of economics, actually. It goes way back into the 1950s when Nobel Prize winner, George Stigler, along with the colleague, David Blank, wrote a book on the demand and supply of engineers. And what's important to me is to—in this kind of work, and also to the people at NSF making the grant, is really to get an understanding of how this part of the labor market works and how it responds to external forces.

For example, I think the market for engineers and scientists will be affected by the radical changes in the outlook for defense spending that have happened just since 1989. Therefore, we want to look in these studies at the response to various kinds of policies of the labor market and the response to different changes in the economic environment, like the growth or non-growth of various high tech industries, the defense component and so forth.

Mr. BOUCHER. One of the criticisms of your data collection efforts and dissemination efforts contained in the NRC report was that information that you collect and analyze is not made available to the research community in a timely way.

Do you have any comment on that statement and what plans do you have to address that. And then, going one step further, would you comment on the recommendation that was made by some of the witnesses on the first panel that it would be helpful if you had

a periodic schedule on which you were required to publish data and disseminate it to those who are interested in receiving it.

Dr. Brown. All right, the schedule—on the dissemination of our research results to the research community, there are a couple of issues there, Mr. Chairman. One is the sheer mechanics of making sure that the people in the research community have something good to work with, that is cleaned-up data tapes. And then a very clear description of what's on the tapes: what do you have here, how do you access it, and is it easy or do you have to spend a month just getting a few numbers out of it. We're working on that, and there we definitely agree with the CNSTAT committee.

Another issue here, however, has to do with privacy, especially on some of these surveys where they ask the person what schools he has degrees from and then proceed to ask him questions about his income and so forth. It would be very easy to look at one of these tapes and to identify people by name even though names are not identified on the tape. We are very concerned about privacy because it was under conditions of privacy and confidentiality that we were able to acquire the information in the first place.

Now, as I say, we are wrestling with this issue and, so far, we have stayed much to the side of privacy. We are still willing to discuss this with the research community; and, if we can find any better ways to release data without compromising privacy and confidentiality, then we'll do it. But it's a delicate—it's a delicate process that we are still working on, and we're still very much in the privacy and confidentiality camp.

Now your next question, I believe, was whether it would be helpful to have schedules of the data released. Frankly, I would say, no. I would much prefer to rely on our own professional competence and our own professional judgement of when these things should come out. I am very much in sympathy with the panel when they say let's get the things out. We don't want data that are obsolete, but just take a couple of examples.

You know, first of all, one of the panelists said that—I think it was Dr. Fechter—that some data need to come out fast, like unemployment rates, and others which don't change very much can afford to come out a little bit more slowly. Some of the other data we do produce have to do with corporate spending on R&D. And those we try to get out very fast, not as fast, however, as some of the surveys that are taken by news magazines. But I think our data are a lot better and a lot more reliable for the extra work we put into them to make sure they're right.

We don't want to be in the position of constantly having to revise data because we put it out too fast, and then something happens to make us go back and have to do it over again. And if you, say, put on a particular schedule and then something legitimately goes wrong, what do you do? I don't quite know how you go about enforcing such rules, I suppose, particularly when obeying the rule would result in the publication of data that could have been better, much better, with just a little more work.

I believe Dr. Ellis, in his testimony, referred a couple of times to something that he called—and I think he was right—a huge anomaly in counting the number of engineers. I don't think that was—that could still happen even if you are not under some kind of

schedule. But I think the problem there was not scheduling. The problem there was giving the data enough competent professional review to see that we really had something that was good.

Mr. BOUCHER. Do you ever get complaints about the timeliness of the dissemination of information from your office?

Dr. BROWN. Oh yes, we do. People would always like to have these things come out a lot faster. There's no doubt about it—

Mr. BOUCHER. So there probably is a community that would applaud having some schedule required for your dissemination?

Dr. BROWN. Well, they would applaud having data come out faster. The thrust of my comment was whether a schedule would cause more problems than it solved with the quality of the data.

Mr. BOUCHER. Okay.

At this time I'd like to yield to my colleague, the ranking Republican member, Mr. Packard.

Mr. PACKARD. Thank you very much, Mr. Chairman.

In your testimony, Dr. Liebman, you mentioned that there are multiple mechanisms and policies through which improved quality in the collection, reporting, and analysis data can be achieved. Would you expand on that briefly, and tell us what steps NSF intends to take to improve quality, and is this issue addressed adequately in the report?

Dr. LIEBMAN. I think that the issue is well addressed in the NRC report and NSF's response to it.

One of the things I hadn't realized until I started looking at this issue is the importance of having individuals outside of NSF have access to the data, because you can get feedback on quality and feedback on definitions.

I think the most difficult issue that—and Dr. Brown referred to it, and I referred to it—is the issue of confidentiality. On the one hand, providing wide user access enables people to tell you what kind of data are important and how good and timely the data are that you are providing. On the other hand, NSF is in a situation now where you can't always comply—you can't provide complete access to the micro data, because individuals can be identified through a combination of schools and incomes.

I think they are doing—I think they are addressing the major quality issues and whether we will ever be able to resolve the confidentiality data—issues, and allow—the one mechanism for improving quality—the broader public access. It's not clear to me they are going to be able to give that in the near future, but that's not because they don't want to, that's because of confidentiality issues.

Mr. PACKARD. Okay, thank you very much.

Dr. Brown, in the NRC report you have indicated that there are serious flaws in the accuracy of the data, particularly the manpower—scientific manpower database. What needs to be done to correct the inaccuracies and the differences between the Bureau of Labor Statistics and NSF, and would it be wise to draw these shortcomings more to the attention of those that would be using them, and provide adequate warnings in terms of those differences or flaws?

Dr. BROWN. Well, sir, there I believe one of the major problems is the question of how you define scientists and engineers. And I think a large part of the problem, indeed, was the complicated definition of an engineer or a scientist that was used in the past in the

NSF studies. It had to do with a complex algorithm by which you would have to satisfy two out of three criteria in order to be counted as an engineer or a scientist and nobody could quite come to—it was very hard to understand. Whereas other—BLS tends to use either an occupational or others use an educational definition. I think a great part of this problem of comparability will be solved when we go to definitions that are more akin to those used elsewhere.

Now the other parts of non-comparability—that is, one part of the Government coming up with much different estimates of the number of engineers than another—go to our sampling techniques, I think. In those matters, too, I think we are making a great deal of progress, and I hope these questions will be largely resolved. The results of our new phase of work comes out in a couple of years.

Mr. PACKARD. How do you determine your samples and how inclusive they will be in terms of women, minorities, foreign nationals, et cetera?

Dr. BROWN. Well, the way we—the way do it to try to—is to first determine what sorts of questions we want to answer.

You're right. We do have a great need to find out more about women and minorities in sciences and engineering, and, indeed, there is a congressionally mandated report that we put out—I believe it's every two years—on precisely that topic. So the way that is done is to make sure that we oversample groups of the population that we know contain the people that are of particular interest to us—and it may also be handicapped people. But just in doing the postcensal survey, for example, we try to oversample those occupations where we know there are a lot of scientists and engineers.

What—there is a second part of your question that I think I've not answered yet.

Mr. PACKARD. I don't recall either, and so I'll let you off—and I was intrigued in your answer.

Do you have much control over the dissemination of the information and the database, or is there a separate agency or group that handles that, and how do you manage it if, in fact, you do that?

Dr. BROWN. Well, we have—we have control of the data and statistics we put out. Of course OMB has authority and must approve our questionnaires before we actually field a survey, but it is—and in some cases some of the data are collected for us by the Census Bureau. And they control a large part of the database, and we take the part that deals primarily with scientists and engineers.

The short answer to your question is, basically NSF controls the data.

Mr. PACKARD. But the dissemination of the data, how is that handled, not to agencies like yourself, but out to those that would use the data in terms of counseling?

Dr. BROWN. Yes, sir. We have a number of ways.

Our primary way of disseminating the data is through our publications. A second way is, we have an electronic means of disseminating these so people can call in and get things in computer form—modem form—rather than having to do them on paper. We make some of the tapes available. Certainly we make tapes available that have no microdata confidentiality problems involved with them, and we try to participate in various kinds of professional so-

cieties and forums to explain to users what source of data we have and what are available to them.

Mr. PACKARD. And what type of users do you have? High schools, universities, industry?

Dr. BROWN. This is one of the things I'm finding out more and more about SRS, that there is just a tremendous range of users for this sort of data. There are the professional societies such as—that are interested in the characteristics of their members, scientists and engineers, and so on; the universities—and I can refer more to Dr. Liebman on this—but they are interested in things pertaining to the market or their students as well as the characteristics of many of their own faculty employees.

We have—just within the Federal Government we believe our numbers support a large amount of very important policy on—science policy, so we have a lot of users right in the Government, not to mention within the National Science Foundation itself. We also have a lot of corporate users of our data, possibly less the kind of data that we are referring to today and more the R&D spending, the facilities surveys, and so forth. We have a very broad range of users and I've probably left out some of them.

Mr. PACKARD. Thank you very much, Mr. Chairman.

Mr. BOUCHER. The Chair thanks the gentleman. And I would only ask one additional question, Mr. Brown, and that relates to the National Research Council's recommendation that your staff receive some measure of inservice training with regard to survey methodology. I wonder if you could tell us what your intention is with regard to implementing that, and tell us if you have ample resources with which to do it?

Dr. BROWN. Well, that was a very clear recommendation of the NRC report, and one that I'm very greatly in sympathy with.

One of the first things I did when I got there this month was to get everybody, including myself, to fill out a form saying what particular computer techniques are you comfortable with and what ones do you need training in. And we very quickly developed an inventory of what we needed to do. We found out we have a lot of—a lot of people know some of the basic things like Lotus 1, 2, 3, but we need more training in basic statistical techniques. That is, the kind of things that people study in statistical departments at the universities. And we need more training in some of the highly complex statistical programs that work on the mainframe computer. On that, I can safely say that we do have the amount of money we need to get the training we need for our staff, and we're in the process of doing that right now.

Mr. BOUCHER. Okay. Anything further?

The Chair would like to thank the witnesses for your helpful testimony here today. This is an intriguing subject, and one that obviously is fundamental to the ability of Congress to make public policy choices, in terms of necessary approaches to stimulating the supply of scientists and engineers. We have to know where we are before we know where we're going, and your testimony today is very helpful in giving us a sense of where we are.

So with the Chair's thanks to this panel and the previous panel, this hearing is adjourned. Thank you.

[Whereupon, at 12:20 p.m., the subcommittee adjourned, to reconvene at the call of the Chair.]

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ISBN 0-16-035793-4

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